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SATELLITE NAVIGATION AND LOCATION SYSTEMS

Background paper 4

The full list of the background papers:

1. The Earth and its environment in space
2. Disaster prediction, warning and mitigation
3. Management of Earth resources
4. Satellite navigation and location systems
5. Space communications and applications
6. Basic space science and microgravity research and their benefits
7. Commercial aspects of space exploration including spin-off benefits
8. Information systems for research and applications
9. Small satellite missions
10. Education and training in space science and technology
11. Economic and societal benefits
12. Promotion of international cooperation

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PREFACE

The United Nations General Assembly, in its resolution 52/56, agreed that the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III) should be convened at the United Nations Office at Vienna from 19 to 30 July 1999 as a special session of the Committee on the Peaceful Uses of Outer Space, open to all Member States of the United Nations.

The primary objectives of UNISPACE III will be:

(a) To promote effective means of using space technology to assist in the solution of problems of regional or global significance;

(b) To strengthen the capabilities of Member States, in particular developing countries, to use the applications of space research for economic and cultural development.

Other objectives of UNISPACE III will be:

(a) To provide developing countries with opportunities to define their needs for space applications for development purposes;

(b) To consider ways of expediting the use of space applications by Member States to promote sustainable development;

(c) To address the various issues related to education, training and technical assistance in space science and technology;

(d) To provide a valuable forum for a critical evaluation of space activities and to increase awareness among the general public regarding the benefits of space technology;

(e) To strengthen international cooperation in the development and use of space technology and applications.

As one of the preparatory activities for UNISPACE III, the Office for Outer Space Affairs of the Secretariat has prepared a number of background papers to provide Member States participating in the Conference, as well as in the regional preparatory meetings, with information on the latest status and trends in the use of space-related technologies. The papers have been prepared on the basis of input provided by international organizations, space agencies and experts from all over the world. A set of 12 complementary background papers have been published and should be read collectively.

Member States, international organizations and space industries planning to attend UNISPACE III should consider the contents of the present paper, particularly in deciding on the composition of their delegation and in formulating contributions to the work of the Conference.

In the preparation of the present paper, contributions from the following organizations have been used: International Civil Aviation Organization, the World Meteorological Organization, the European Space Agency, the International Mobile Satellite Organization, the Department of Space of the Government of India, the Indian Space Research Organization and the Russian Space Agency.

The assistance of M. J. Rycroft (International Space University, Strasbourg, France, and Cambridge University, United Kingdom of Great Britain and Northern Ireland) as technical editor of background papers 1-10 is gratefully acknowledged.

SUMMARY

The Global Navigation Satellite System (GNSS) is a space-based radio positioning system that includes one or more satellite constellations, augmented as necessary to support the intended operation, and that provides 24-hour three-dimensional position, velocity and time information to suitably equipped users anywhere on, or near, the surface of Earth (and sometimes off Earth). There are two core elements of satellite navigation systems: the Global Positioning System (GPS) (operated by the United States of America) and the Global Orbiting Navigation Satellite System (GLONASS) (operated by the Russian Federation).

Satellite navigation uses satellites as reference points to calculate positions accurate to within metres. With advanced forms of satellite navigation, measurements can be made down to the centimetre level.

The main advantages of satellite navigation and positioning are economy and better services, largely but not limited to the transport area. New applications are emerging frequently in a wide variety of sectors as technology continues to evolve. The future of satellite navigation is unlimited.

GNSS receivers have been miniaturized to just a few integrated circuits and are becoming very economical, making the technology accessible to virtually everyone. GNSS technology has matured into a resource that goes far beyond its original design goals. Currently, scientists, sportsmen, farmers, soldiers, pilots, surveyors, hikers, delivery drivers, sailors, dispatchers, lumberjacks, firefighters and people from many other professions are using GNSS in ways that make their work more productive, safer and sometimes even easier. GPS equipment is being built into cars, boats, planes, construction equipment, movie-making gear, farm machinery and even laptop computers. Soon, satellite navigation will become a universal utility.

The fast-growing worldwide market for GNSS receivers is currently approaching an annual turnover of 2 billion United States dollars ($) and is expected to reach $8 billion by 2000. Conservative estimates for the markets of value-added services indicate that they will be at least of the same size as the receiver market.

Both GPS and GLONASS were developed for military purposes and remain under the military control of the United States and the Russian Federation. However, the use of these two existing military satellite navigation systems has been offered free of charge to civil users. Currently, neither system meets the requirements of all user categories, civil aviation in particular, and both need to be enhanced with system augmentations; preparatory work towards a follow-on system has been initiated.

While the implementation of existing systems in the development of a future global satellite navigation system can now get under way, there are still a number of political, institutional, legal and economic problems to be resolved before any new type of system can be deployed.

I. BRIEF HISTORY OF RADIO NAVIGATION SYSTEMS

1. Radio navigation had its origin in the 1920s. The earliest systems were based simply on the ability of a radio receiver with a loop antenna to determine the direction of arrival of a radio signal and the relative bearing to the transmitter. Later, several radio navigation systems relied on ground transmitters sending modulated

signals characteristic of the direction of transmission. Other radio systems determined the direction and/or range from the navigator equipment to a fixed transmitter.

2. There have also been long-range navigation systems that measure the difference in time between signals received from synchronized pairs of transmitters at different locations or phase differences between continuous-wave transmissions from pairs of transmitters.

3. Ground-based navigation transmitters operate over a wide range of frequencies. Low-frequency radio waves are not easy to modulate, and are subject to errors due to the ionosphere and weather disturbances. High-frequency radio is limited to line-of-sight range, so that many on-land transmitter sites are required and transmitters are impossible to position at sea. A satellite, however, is an ideal location for a radio navigation transmitter, and a constellation of satellites, in appropriate orbits, can cover Earth with navigation signals. Satellites were first used for position finding in a system called TRANSIT.

II. OVERVIEW OF SATELLITE NAVIGATION

A. Global Positioning System

4. GPS is the most recognized term describing satellite navigation systems; however, it is only one of several elements falling under the umbrella of GNSS. Satellite navigation uses satellites as reference points to calculate positions accurate to a matter of metres. With advanced techniques and augmentations, satellite navigation can make measurements down to the centimetre level.

5. GNSS receivers have been miniaturized to just a few integrated circuits and are becoming very economical, making the technology accessible to virtually everyone. GPS is currently being built into cars, boats, planes, construction equipment, movie-making gear, farm machinery and even laptop computers. Soon GPS will become a universal utility.

6. Satellite navigation is a space-based radio positioning system that includes one or more satellite constellations, augmented as necessary to support the intended operation, and that provides 24-hour three-dimensional position, velocity and time information to suitably equipped users anywhere on, or near, the surface of Earth (and sometimes off Earth). A satellite navigation system provides users with sufficient accuracy and integrity of information to be useable for critical navigation applications. The GPS system is the first core element of the satellite navigation system widely available to civilian users. The Russian satellite navigation system, GLONASS, which is similar in operation, is another satellite constellation element of GNSS.

7. These systems promise to bring radical improvements to many other systems that have an impact on the lives of everyone. By combining GNSS with current and future computer mapping techniques, the identification and management of natural resources will be improved. Intelligent vehicle location and navigation systems will enable car and truck users to avoid congested freeways and find more efficient routes to their destinations, saving millions of dollars in petrol and tonnes of air pollution. Travel aboard ships and aircraft will be safer in all weather conditions. Businesses with large amounts of outside plants (for example, railroads and utilities) will be able to manage their resources more efficiently, thereby reducing consumer costs.

8. Accurate mapping and surveying is another area in which GPS is expanding. Mapping and surveying companies use GPS extensively. In wildlife management, endangered species are being fitted with GPS receivers and tiny transmitters to help determine population distribution patterns and possible sources of disease.

9. GPS-equipped balloons are monitoring holes in the ozone layer over the polar regions, and air quality is being monitored using GNSS receivers. Buoys tracking major oil spills transmit data using GNSS. Archaeologists and explorers are using the system. The future of GNSS is unlimited. New applications will continue to be created as technology evolves. As the cost of GNSS receivers continues to drop, more and more entrepreneurs will invent further uses for the system.

10. GPS is a satellite-based navigation system developed and operated by the United States Department of Defense. GPS permits land, sea and airborne users to determine their three-dimensional position, velocity and time. The service is available to military and civilian users around the clock, in all types of weather, anywhere in the world.

11. GPS uses the Navigation Satellite Providing Time and Range (NAVSTAR) satellites. The current constellation consists of 21 operational satellites and 3 active spares. The GPS system is now fully operational. Satellites are in orbits with approximately 12-hour periods operating at an altitude of 20,200 kilometres. The orbital constellation consists of six orbital planes, each inclined with respect to the equatorial plane by about 55 degrees. Such an arrangement ensures that at any time there are at least four (and up to 12) satellites above the horizon available for simultaneous measurements.

12. GPS receivers are therefore able to instantly solve four equations to determine latitude, longitude, altitude (with reference to mean sea level) and time. GPS is not only a positioning tool but probably the best timing system available. Atomic clocks inside the satellites stabilize the signals that are transmitted. Those signals allow user time to be determined within an accuracy of 0.1 microsecond.

13. GPS works in very logical steps; each of the orbiting satellites beams a continuous radio signal to Earth, which is received by a GPS receiver in order to derive distances by measuring the travel time of the radio signals. The travel time can be measured extremely accurately because of the very accurate timing devices aboard each satellite, and corrections to the result account for any delays which the signal experiences as it travels through the ionosphere and the atmosphere.

14. The GPS satellite signal contains information used to identify the satellite, as well as the position, timing, ranging data, satellite status and updated ephemeris (orbital parameters). The satellites are identified by either the space vehicle number or the pseudo-random code number.

15. GPS satellites transmit on two L-band frequencies: 1.57542 GHz (L1) and 1.22760 GHz (L2). The L1 signal has a sequence encoded on the carrier frequency by a modulation technique which contains two codes, a precision (P) code and a coarse/acquisition (C/A) code. The L2 carrier contains only P-code that is encrypted for military and authorized civilian users. Most commercially available GPS receivers utilize the L1 signal and the C/A code.

16. P-code users determine their geocentric positions instantly to about 5 metres with a single hand-held satellite receiver. The military has encrypted the P-codes by altering the underlying mathematical formula and only authorized users know what the change is. As a consequence, civilian users cannot observe the P-codes directly.

17. The C/A codes repeat every millisecond and are available to every user. These codes are also usable for positioning but they provide only about 20- to 30-metre accuracy. The military has built another feature into the system: selective availability. The combined effect of selective availability, that is, both clock dither and tinkering with the navigation message, degrades the position accuracy of single-receiver users to about 100 to 150 metres. This is an officially sanctioned policy.

18. GPS is at present wholly financed and operated by the military, but many technological developments of GPS positioning were driven by the civilian sector. Typically, civilian users strive to achieve the highest position accuracy. Some techniques rely on two stations that co-observe GPS satellites simultaneously and provide for an almost unbelievable accuracy of 1 centimetre in 10,000 kilometres. Such accuracy is primarily of scientific interest for studying Earth crustal deformations and tectonic plate motions, for example.

19. While static GPS techniques with stationary receivers are very useful in many cases, GPS works equally well when one or both receivers are in motion, through kinematic GPS techniques. The applications of accurate kinematic positioning are unlimited.

20. The GPS control segment consists of a worldwide system of tracking and monitoring stations. The monitoring stations measure signals from the GPS satellites and relay the information collected to the master control station. The master control station uses the data to compute precise orbital models for the entire GPS constellation. The information is then formatted into updated navigation messages for each satellite.

21. The user segment consists of the GPS receivers, processors and antennas utilized for positioning and timing. The user's receiver measures the time delay for the signal to reach the receiver. By knowing the distance to four points (the satellites) in space, the GPS receiver is able to triangulate a three-dimensional position (latitude, longitude and height).

B. Differential Global Positioning System

22. A system was developed to improve GPS accuracy even further. Differential GPS (DGPS) is GPS with an additional correction signal added. DGPS uses a reference station at a known point to calculate and correct bias errors. The reference station computes corrections for each satellite signal and broadcasts these corrections to the remote GPS receiver. The remote receiver then applies the corrections to each satellite used to compute its fix.

23. DGPS can yield measurements to a couple of metres accuracy in moving applications and even better in stationary situations. That improved accuracy has a profound effect on the importance of GPS as a resource. With it, GPS becomes more than just a system for navigating boats and planes around the world. It becomes a universal measurement system capable of positioning things on a very precise scale.

24. Real-time differential GPS makes use of a base station located over a known control point where it is continuously computing the difference between its known and its reported position every second or so. It then sends this correction information to a radio transmitter, which broadcasts the correction information over an existing broadcast frequency. The GPS receiver of the user needs to have a second radio receiver that will receive the differential broadcast, and that will correct the recorded position for the position recorded 1 or 2 seconds previously. Because the errors in the system, or rover, do not simply jump about randomly, but "fade" in directional patterns, the systems can provide real-time positioning at the required accuracy of 2-5 metres.

25. Carrier-phase GPS is a second method of position determination capable of providing centimetre positional accuracy, and is used extensively in the surveying and geodetic communities for the creation of precise surveying monuments and geodetic controls. It tracks and records the 19-centimetre radio waves, corresponding to the carrier frequency L1, transmitted from the satellites. The receivers are much more complex and expensive than the hand-held code-based GPS receivers. One receiver is placed over a known geodetic survey marker, while a second is placed where the new control point or marker is needed. This technique is rapidly becoming the means of conducting centimetre accuracy surveying for a variety of practical and scientific purposes, including photogrammetry, aerial survey controls, and even measurements of minute movements of Earth plates or volcanic lava domes.

C. Global Orbiting Navigation Satellite System

26. GLONASS has much in common with GPS in terms of the satellite constellation, orbits and signal structure. Both transmit spread spectrum signals at two frequencies in the L-band (1.2 GHz and 1.6 GHz), and have pledged to make a partial set of signals available for civil use without any user fees for at least the next 10 years. The GLONASS satellites are deployed in three orbital planes. GPS satellites transmit at the same carrier frequency using codes that are orthogonal; GLONASS satellites transmit the same code but at different frequencies.

27. Unlike GPS, GLONASS does not have intentional signal degradation for civil use. The differences in the quality of the position estimates available from GPS and GLONASS are mainly due to this purposeful degradation of the GPS signals, known as Selective Availability. Like GPS, GLONASS offers two levels of service. The Channel of Standard Accuracy, available to all civil users, provides horizontal position accuracy of 60 metres and vertical position accuracy of 75 metres. The Channel of High Accuracy is available only to authorized users.

28. GLONASS is still under development. In January 1996, for the first time, the system had a full constellation of 24 working satellites. That year, new GLONASS receivers also began to appear on the market. However, no satellites were launched in either 1996 or 1997 and the number of operational satellites in the constellation as of the beginning of 1998 stood at 13.

29. The GLONASS constellation is operated by a ground-based control complex. It consists of the system control centre (SCC) and several command tracking stations (CTS) which are placed over a wide area of the Russian Federation. CTS track the GLONASS satellites in view and accumulate ranging data and telemetry from the satellite signals. The information from CTS is processed at the SCC to determine satellite clock and orbit states and to update the navigation message of each satellite. This updated information is transmitted to the satellites via CTS, which are also used for the transmitting of control information.

30. Important benefits could accrue to the users of GPS from the additional signals of an operational GLONASS system. The principal benefit would be in the form of robustness of the combined system in the sense that small perturbations in either GPS or GLONASS are unlikely to have a serious impact on any particular user. The source of this benefit is the increased number of satellites in view. Even with a conservative assumption that GPS and GLONASS each would maintain a 21-satellite constellation, all users are assured of a minimum of eight satellites in view above a 7.5 elevation angle; 99 per cent of the global users are assured of 10 satellites in view; and half the users would see 14 or more satellites.

31. An operational GLONASS would remove a serious concern of current GPS users of a single point of failure, technically or politically. The two systems transmit at different frequencies, offering greater immunity to radio frequency (RF) interference, intentional or inadvertent. Such immunity is further enhanced by the frequency diversity of the GLONASS signals. The consideration of robustness is vital to the use of a system in any regular, ongoing operation, especially one that may entail issues of safety. A characterization of the robustness may take the form of integrity of position estimates, continuity and availability of GNSS service under conservative assumptions regarding perturbations to the operation of the system.

32. To improve GNSS performance to satisfy requirements of critical safety applications, various satellite-based and ground-based augmentations are being developed. One way to provide augmentation coverage over large areas is to use satellites, for example, in geostationary orbit, to transmit differential correction and/or integrity messages to the users. This type of augmentation system includes the European Geostationary Navigation Overlay Service (EGNOS) (European Union), Wide Area Augmentation System (WAAS) (United States) and MSAS (Japan).

D. European Geostationary Navigation Overlay Service

33. In view of the investments made by a large variety of users and with the goal of developing the use of navigational signals, Europe has decided to implement an initial GNSS based on a regional augmentation of GPS and GLONASS and to initiate, in parallel, preparatory work towards a follow-on system.

34. The European contribution to a GNSS is based on the use of navigation payloads on geostationary satellites (two Inmarsat-3 and Artemis of the European Space Agency), and is referred to as EGNOS. The EGNOS system will meet, in particular, civil aviation navigation requirements for all phases of flight, from en route to precision approach and landing.

35. Inmarsat-3 satellites are equipped with navigation transponders to receive navigation signals of both GPS and GLONASS systems from a ground station which are then broadcast to users. The navigation package will provide four different services: (i) integrity monitoring; (ii) geostationary ranging augmentation; (iii) wide area differential corrections; and (iv) precision time reference. The International Mobile Satellite Organization (Inmarsat) intends to provide similar, but enhanced, navigation capability on its future generations of satellites.

36. The second-generation GNSS is expected to be under civilian control, tailored to the long-term needs of civil user communities and designed for improved navigation performance, while still retaining GPS/GLONASS backward compatibility. From a technical point of view, the second generation of GNSS will represent a significant improvement for civil users. The system will have to be designed to serve the needs of civil users in 2005-2020, and it is anticipated that the demand for improved integrity, accuracy and availability will increase. A future GNSS will have to address the needs of all transportation means, whether on land, railway, sea or air, as well as the needs of space systems. It will most likely include enhanced broadcast capabilities and be associated with complementary communications functions, which will be needed for telematics applications (road traffic reporting and forecasting, as well as fleet management systems) and automatic dependent surveillance for air traffic management. Several system options may be considered for GNSS-2: a low-Earth-orbit or a medium-Earth-orbit constellation, with or without a geostationary-Earth-orbit complement. The second-generation GNSS could be introduced as a supplementary means of navigation in 2005-2010 and later operate as the primary means for all flight phases in 2010-2015. From an institutional point of view, GNSS could be jointly developed with some or all the major partners (specifically the United States and the Russian Federation), or independently by the European Union on either a regional or global basis.

III. RELATED SYSTEMS

A. Search and rescue system

37. The International Search and Rescue Satellite System (COSPAS-SARSAT) consists of a constellation of satellites in polar orbit and a network of ground receiving stations that provide distress alert and location information to appropriate rescue authorities for maritime, aviation and land users in distress.

38. The COSPAS-SARSAT system provides distress alert and location data to rescue coordination centres, to beacons at a frequency of 121.5 MHz within the coverage area of COSPAS-SARSAT ground stations (local user terminals), and to beacons operating at 406 MHz and which may be activated anywhere in the world. Complete coverage of Earth, including the polar regions, can be achieved using simple emergency beacons to signal distress.

39. There are three types of radio beacons, namely aviation emergency locator transmitters, maritime emergency position-indicating radio beacons and personal locator beacons. The beacons transmit signals that

are detected by COSPAS-SARSAT polar-orbiting spacecraft equipped with suitable receivers. The signals are relayed to COSPAS-SARSAT local user terminals which process the signals to determine the beacon location. Alerts are then relayed, together with location data, via a mission control centre (MCC), either to another MCC or to the appropriate search and rescue point of contact or rescue coordination centre.

40. Doppler location (using the relative motion between the spacecraft and the beacon) is the means used to locate these very simple devices. The carrier frequency transmitted by the beacon is reasonably stable during the period of mutual beacon-satellite visibility. The frequencies currently in use are the 121.5 MHz aeronautical emergency frequency, also allocated to distress beacons, and frequencies in the 406.0-406.1 MHz band exclusively reserved for distress beacons operating with satellite systems.

41. Since 1982, the system has been used for over 2,000 search and rescue events, and has been responsible for saving over 7,000 lives worldwide. COSPAS-SARSAT is currently considering the use of a geostationary Earth orbit search and rescue (GEOSAR) satellite capability as a potential enhancement to the existing polar-orbiting system. In recent years, COSPAS-SARSAT participants have been experimenting with 406 MHz payloads on geostationary satellites together with experimental ground stations. These experiments have shown the possibility of almost immediate alerts with identity at 406 MHz. COSPAS-SARSAT has developed a GEOSAR demonstration and evaluation plan.

B. ARGOS

42. ARGOS is a satellite-based location and data collection system dedicated to monitoring and protecting the environment. ARGOS provides the location of any platform equipped with a suitable transmitter, anywhere in the world, to within 150 to 1,000 metres. Data can also be collected from sensors connected to the transmitter. Over 5000 ARGOS transmitters are now operating around the world. The ARGOS system has been operational since 1978. It was established under an agreement between the National Oceanic and Atmospheric Administration (NOAA) of the United States, the National Aeronautics and Space Administration of the United States and the Centre National d'Études Spatiales (French National Centre for Space Studies).

43. The system utilizes both ground- and satellite-based resources to accomplish its mission. They include instruments carried on board the NOAA polar-orbiting operational environmental satellites, receiving stations around the world and major processing facilities in France and the United States. The fully integrated system works to locate conveniently and deliver data from the most remote platforms to the user desktop, often in near real time.

44. ARGOS is easy to use. A transmitter starts sending signals as soon as it is switched on. One of the system satellites collects the data and retransmits them to the ARGOS centres for processing. Accessing data is just as easy. The results can be retrieved from anywhere in the world by public data networks, often within 20 minutes of transmission.

45. Another attractive feature of the ARGOS system is the small transmitters: the average daily electric current required is as low as a few milliamperes; miniaturized models can be as compact as a small matchbox, weighing as little as 20 grams. Such features mean that ARGOS can be used to track small animals.

46. ARGOS is used to collect data and provide locations for many applications involving environmental protection, including tracking fishing-vessel fleets throughout the world, monitoring the movement of hazardous or dangerous materials, monitoring pipeline systems for leaks or the failure of protection systems, monitoring oil spills or predicting spill movements, and monitoring other types of pollution.

47. India has been using its own Indian National Satellite (INSAT) platforms to obtain meteorological data from unattended remote locations by installing a data relay transponder on board its geostationary satellites. Recently the use of the data collection platforms has also been extended to monitor flood levels in some of the major rivers of the country.

C. DORIS

48. The DORIS (France) system comprises an on-board package, a beacon network and a control and data-processing centre to perform its dual mission of spacecraft orbit restitution and ground beacon location. It is based on the accurate measurement of the Doppler shift on radiofrequency signals emitted by ground beacons and received on board the spacecraft. Measurements are made on two frequencies, 2036.25 MHz for accurate Doppler measurement and 401.25 MHz for ionospheric correction. The 401.25 MHz frequency is also used for measurement time-tagging and auxiliary data transmission.

49. Selection of an uplink system allows for fully automated operation of the beacons and easy communications links for the overall system, the data being centralized through the satellite and its ground segment to the DORIS data-processing centre. DORIS on-board is currently flying on the SPOT-2 and SPOT-3 Earth observation satellites and TOPEX oceanography satellite, and is scheduled to fly on SPOT-4 in 1998 and ENVISAT, SPOT-5 and TOPEX follow-on satellites.

50. The ground segment is shared by all DORIS missions. The orbit determination beacons are deployed in a dense worldwide network. For the point-positioning mission of DORIS, specific ground location beacons are available and are installed according to different user needs. They are field-packaged and equipped with autonomous power supplies.

D. Satellite Laser Ranging

51. Satellite Laser Ranging (SLR) is a technique to measure the range or distance between a laser station on Earth and an orbiting satellite equipped with special mirrors (retro-reflectors), to a precision of less than 1 centimetre. When multiple laser stations are globally distributed and collect data from the same satellite, the precise position of that satellite can be determined along with the positions of the laser stations. That technique is called precision orbit determination. By tracking satellites for several years, not only can the distance between the laser stations be calculated to a few millimetres, but also the rate of motion between the lasers can be monitored to the same precise level. SLR data are also used in numerous other scientific applications, including studies of the Earth/atmosphere/ocean system, geophysics and transferring time standards between continents.

52. The precision of the measurements is a function of the laser tracking system and the satellite retro-reflector array, and may be at the level of 1-3 millimetres, as is the case for the Laser Geodynamic Satellite (LAGEOS). Such precision is achieved through statistical compression of the data.

53. The applications of SLR data from geodetic satellites include detection and monitoring of tectonic plate motions, crustal deformation, Earth rotation and polar motion; modelling of the spatial and temporal variations of the Earth gravitational field; determination of basin-scale ocean tides; monitoring of millimetre-level variations in the location of the centre of mass of the total Earth system (solid Earth/atmosphere/oceans); establishment and maintenance of the International Terrestrial Reference System; detection and monitoring of post-glacial rebound and subsidence; and monitoring the response of the atmosphere to seasonal variations in solar heating.

54. SLR data from remote sensing satellites combined with data from several other tracking techniques together will yield accurate ocean basin topographic maps. The data will permit quantitative studies of changes

in ocean currents, which are crucial to understanding global climate change. SLR data will also be used to calibrate the radar altimeters on board the spacecraft. In addition, SLR has proven to be a cost-effective means of providing fail-safe redundancy to spaceborne radiometric tracking systems such as GPS, DORIS and precise range and range rate equipment (PRARE).

55. SLR data from positioning satellites is used to improve the accuracy of the International GPS Service Network and to improve the transfer of time between the GPS and GLONASS satellites and the GPS and GLONASS receivers.

IV. APPLICATIONS OF THE GLOBAL POSITIONING SYSTEM

56. The first and most obvious application of GPS is the simple determination of position or location. GPS is the first positioning system to offer highly precise location data for any point on the planet, in any weather. That alone would be enough to qualify it as a major utility, but the accuracy of GPS and the creativity of its users is pushing it into some surprising realms.

A. Aviation applications

57. GNSS is a main element of the International Civil Aviation Organization communications, navigation, surveillance and air traffic management system providing worldwide navigation coverage to support all phases of flight. With appropriate augmentation systems, GNSS will enable gate-to-gate navigation and all-weather operation capabilities for suitably equipped aircraft. The full implementation of GNSS will offer the possibility of dismantling some or all of the existing ground-based aeronautical systems.

58. By providing more precise navigation tools and accurate landing systems, GNSS makes flying not only safer, but also more efficient. With precise point-to-point navigation, GNSS saves fuel and extends the range of an aircraft by ensuring that pilots do not stray from the most direct routes to their destinations. GNSS accuracy will also allow closer aircraft separations on more direct routes, which in turn means more efficient use of airspace. The United States Federal Aviation Administration is actively working with DGPS beacons for use in en route navigation, precision approach and landings, and for mapping the precise locations of aircraft on the ground while they taxi to and from runways.

B. Maritime use

59. In general, mariners use GPS for either navigation or positioning, although GPS has recently been applied to surveillance as well. GPS and DGPS are used to provide accurate positioning information that is integrated with other positioning, communications and computing technologies.

60. A maritime real-time DGPS system is being put in place by the United States Coast Guard. It consists of a series of DGPS base stations that transmit over an existing maritime homing beacon system. Plans are to establish a complete series of 45 such DGPS beacons throughout the United States. An operational DGPS beacon system is already working in Scandinavia, and more are being established, some using FM radio sidebands to carry the data, doing away with the need for dedicated beacons.

C. Land transportation applications

61. Many automotive GPS applications fit within the description of intelligent transportation systems (ITS). ITS programmes are intended to: (i) improve traveller safety; (ii) improve travel efficiency by reducing

congestion; (iii) save energy though reduction of gasoline requirements; and (iv) lessen the environmental impact of travel.

62. Automobile navigation applications help the driver to make the most efficient routing decisions. Some automobile manufacturers are offering moving-map displays guided by GPS receivers as an option on new vehicles. The displays can be removed and taken into the home to plan a trip.

63. A relatively recent trend is the use of GPS systems in connection with car-mounted cellular telephones to automatically locate cars involved in accidents. In this system, a microcomputer monitors the airbag deployment system installed in new cars. If it detects that the airbag has deployed, the computer calls a service centre over the cell phone of the car, passing to it the last known location of the car as determined by the GPS receiver. The service centre then passes the information to local emergency services, which can then respond.

64. Many companies maintain large fleets of vehicles. Two of the problems associated with maintaining such a fleet consists in knowing the current location and physical condition of any given vehicle. Fleet tracking systems are concerned with addressing those two issues. A fleet tracking system consists of the following:

(a) A vehicle locating device. In some systems, GPS receivers perform that function. Other systems, such as Loran, may be used. Systems such as the Omnitracs service use proprietary satellite-based location systems provided by Qualcomm;

(b) A vehicle-mounted communications device. The vehicle being tracked must be able to transmit its location back to the fleet control centre by some means. Some national fleet management systems use low bit-rate satellite data networks. Others may use some form of cellular telephony. Fleets located in small, geographically contiguous areas may use VHF or UHF two-way radio. The communications module may have additional components allowing the condition of the vehicle to be monitored and short messages to be passed to and from the driver of the vehicle;

(c) A communications network. Data being transmitted from the vehicle may be relayed back to the fleet management by any of several different means. Proprietary satellite communications systems may require dedicated leased data lines from the satellite service provider. Cellular telephone-based tracking systems may rely on the public telephone systems. VHF and UHF radio systems used by police, fire and ambulance systems may use city-owned and -maintained data networks, or possibly packet radio;

(d) A computerized information system. Information on the location and condition of the vehicle is imported into a computer system. The system may be designed to monitor the vehicle autonomously and alert the fleet manager in the event of anomalies.

D. Mapping, geodesy and land surveying (carrier-phase tracking) applications

65. Using GPS to survey and map precisely saves time and money in this most stringent of all applications. Today, GPS equipment makes it possible for a single surveyor to accomplish in a day what used to take weeks with an entire team. And the work can be completed with a higher level of accuracy than ever before.

66. For hundreds of years, surveyors have relied on optical instruments and physical measuring devices. Optical instruments (and newer electronic distance measuring instruments) require a direct line of sight from the instrument to a target. Measuring tapes or chains require that the survey crew physically pass through all the intervening terrain to measure the distance between two points. The big advantage of GPS is that the line of sight does not have to be established between two stations. Thus, surveying can be done in almost all weather

conditions or on opposite sides of a mountain. Another advantage is that the accuracy of the collected data is not as dependent on the skill of the instrument operator as previously.

67. Because the line of sight does not have to be established between GPS stations, major cost savings can be realized in large projects involving a large number of survey teams over a limited area. A single GPS receiver can be set up as a reference station which can be used by any number of surveyors, each of which can be working on a separate job. That contrasts with conventional survey equipment, for which at least two people must be working on the same job (one for each end).

68. Carrier-phase tracking of GPS signals has resulted in a revolution in land surveying. A line of sight along the ground is no longer necessary for precise positioning. Positions can be measured up to 30 kilometres from a reference point without intermediate points. Such a use of GPS requires specially equipped carrier tracking receivers.

69. The L1 and/or L2 carrier signals are used in carrier phase surveying. L1 carrier cycles have a wavelength of 19 centimetres. If tracked and measured, the carrier signals can provide ranging measurements with relative accuracies of millimetres under special circumstances.

70. Tracking carrier-phase signals provides no information on the time of transmission. The carrier signals, while modulated with time-tagged binary codes, carry no time-tags that distinguish one cycle from another. The measurements used in carrier-phase tracking are the differences in carrier-phase cycles and fractions of cycles over time. At least two receivers track carrier signals at the same time. Ionospheric delay differences in the two receivers must be small enough to ensure that the carrier-phase cycles are properly accounted for. That usually requires the two receivers to be within about 30 kilometres of each other.

E. Earth science applications

71. A common goal in the Earth sciences is to understand dynamic and often complex processes. While some Earth science investigations aim at extracting an accurate record of the past, GPS provides a unique opportunity to measure ongoing Earth processes in diverse environments. The evolution of Earth science made possible by GPS over the last decade has been dramatic.

72. An initial goal of the Earth science community was to use GPS to test models of plate kinematics predicted by the plate tectonic paradigm. The predictions were based on the interpretation of marine magnetics, hot spot traces and earthquake focal mechanisms, and are the foundation for much of geoscience research today. Plate kinematic studies with GPS provided detailed observations of plate motions, confirming the geological models, and extending them to regions where constraints from geologic data were weak.

73. The efforts of the Earth science community now focus on using the improved resolution available from GPS to document increasingly complex phenomena in Earth systems. Many of the scientific goals of today would have been unattainable in the early days of GPS studies. Problems being addressed include variations of strain throughout the earthquake cycle, volcanic processes, ice dynamics and sea-level change, and sea-floor geodesy.

F. Meteorological and climate applications

74. GPS has made a huge contribution to the meteorological and climate aspects of environmental monitoring and has a tremendous potential to contribute much more. In the field of operational meteorology, it has already become the prime system for determining position information for balloon soundings, and hence for measuring

balloon height and obtaining wind-speed information. Ground-based GPS receivers can provide an estimate of the total precipitable water in the column above the receiver and hence the total latent heat available.

75. Satellite-based receivers can measure vertical profiles of temperature from 5 to 40 kilometres and above using the so-called radio-occultation approach, where the refraction of the GPS signal through the atmospheric limb is determined twice per receiver orbit for every GPS satellite. That can provide as many as 500 profiles per day, uniformly distributed around Earth, and thus offers the exciting prospect of complete global coverage in space and time from a constellation of receivers used in conjunction with a subset of the current costly radiosonde system. This space-based application of the GPS system has been named GPS/MET, and continuing research will extend its capabilities beyond the current highly promising results.

76. GPS/MET will also make a major contribution in climate monitoring in that it can provide long-term, accurate, consistent measurements of mean temperatures on both regional and global scales, which are very difficult or impossible to make from Earth-based sensors. Measurements of stratospheric temperatures will contribute to an understanding of the ozone problem, particularly with respect to predicting the formation of polar stratospheric clouds in conditions of extreme cold. Data from GPS limb sounding may also be useful in the study of gravity waves that transport energy and momentum throughout the middle atmosphere, thereby contributing further to global change research.

77. In the area of data collection, the ARGOS system on the polar-orbiting meteorological satellites and the data-forwarding capabilities of the geostationary satellites are indispensable for the collection and location of environmental data for a variety of applications from fixed and moving platforms around the globe.

G. Atmospheric sensing and sounding

78. The GPS signal is sensitive to the refractive index of the atmosphere. This index is a function of pressure, temperature and moisture. Therefore, GPS can be used to sense properties of the atmosphere. Since small amounts of atmospheric water vapour significantly affect GPS signal propagation velocities, GPS is especially well suited for sensing atmospheric water vapour, which plays a major role in atmospheric processes ranging from global climate change to micrometeorology.

79. While atmospheric sensing techniques with GPS have been developed to achieve better vertical surveying accuracies, future research regarding the use of GPS to monitor atmospheric water vapour may benefit solid Earth science as well. Permanent GPS stations for weather monitoring are now under development. Those stations will enhance the current crustal deformation networks, and improved understanding of atmospheric water vapour may lead to additional improvements in GPS surveying. Data from the atmospheric stations will be made available for high-accuracy GPS orbit determination and may provide more accurate GPS orbits.

80. Kinematic GPS techniques can be used to locate aircraft accurately in flight. If the position of the aeroplane, and more importantly its vertical acceleration and tilt, can be monitored with GPS, airborne gravimetric measurements can be corrected for non-gravitational accelerations. Once it is possible to correct airborne gravimetric measurements to the order of 1 milligal with 1-kilometre resolution, then airborne gravimetric data will become a very useful and powerful tool for scientific research and natural resource exploration.

H. Agriculture

81. Recently farmers have gained access to site-specific technology through GPS. GPS can identify the location of farm equipment to within a metre of an actual site in the field. The value of knowing precise locations to within a few centimetres is that: the location of soil samples and laboratory results can be compared

to a soil map; fertilizer and pesticides can be prescribed to fit soil properties (clay and content of organic matter) and soil conditions (relief and drainage); tillage adjustments can be made as conditions across the field vary; and yield data across a field can be monitored and recorded.

82. A computerized soil map of a specific field on a computer fitted to a tractor along with GPS can tell farmers where they are in the field and give them the opportunity to adjust the seeding rate as they go across their fields. Using GPS along with a digital drainage map, farmers can apply pesticides more safely. The spraying equipment can be pre-programmed to turn off automatically when it reaches a distance limitation, or zone of a drainage feature. Additionally, farmers can pre-program the rate of pesticide or fertilizer to be applied so that only the amount needed determined by the soil condition is applied; this rate can be varied from one area of the field to another, saving money and allowing for safer use of the materials.

83. The use of GPS in making equipment adjustments to different soil types would mean higher yields and safer production at lower costs. This part of precision farming is still in its inception phase. The equipment companies will be announcing tillage equipment with GPS and selected controls tailored to precision farming in the near future.

I. Timing and telecommunications applications

84. As a universal marker, time indicates when things happened or when they will happen. As a way to synchronize people, events, even other types of signals, time helps to keep the world on schedule. And as a way to tell how long things last, time provides an accurate, unambiguous measure of durations.

85. GPS satellites carry highly accurate atomic clocks. In order for the system to work, GPS receivers on the ground synchronize themselves to these clocks. That means that every GPS receiver is, in essence, an atomic accuracy clock. Astronomers, power companies, computer networks, communications systems, banks, and radio and television stations can benefit from this precise timing capability.

86. Because the pseudo-ranging method used by GPS to establish three-dimensional position locations requires a highly accurate time standard, the system is ideally suited for applications that require precision timing and precise time transfer. GPS pseudo-range measurements are based on the transit time of a signal from the GPS satellite to the user. Thus, if the locations of both the satellite and the observer are known, the difference in the user-clock offset from that of the satellite can be readily determined.

87. The time-transfer community was one of the first to realize the benefits of GPS, since a full satellite constellation is not required for most time-transfer methods. In fact, the most accurate method of time transfer to date, known as GPS common-view, relies on the ability of two users on the globe to observe the same GPS satellite simultaneously, despite a large geographic separation. GPS common-view is currently used by the 55 international timing centres that are charged with the task of maintaining International Atomic Time and Universal Time Coordinated (UTC) throughout the world.

88. GPS is also increasingly utilized by many telecommunications companies to synchronize their land-based digital telecommunications networks. Most often, these users compare a reference clock directly to GPS time by viewing one or more satellites, rather than transferring time from one reference clock to another.

89. Precise GPS timing also has the potential to improve mobile cellular communications significantly. Currently most cellular telephone networks are subject to transmission degradation as a call is transferred from one cell channel to another; if all the cells of a network used the same channel, the problem would be eliminated. This can be accomplished by providing each cell with a unique code rather than a unique frequency using a technique known as Code Division Multiple Access (CDMA). Major CDMA manufacturers have

recognized GPS as an effective way to provide the precise time synchronization required by their systems. Timing accuracies similar to those required for digital networks are sufficient for this application.

90. Cellular signals are also subject to local conditions in each cell, such as weather or landform geometry, and these may vary from cell to cell. By putting GPS positioning capability into the mobile receiver and by transmitting the position information to the mobile control and operations centre of the mobile system, the network control operations could determine user location and travel direction. With that information available, the network controller can provide optimal handovers as well as real-time dynamic performance optimization for each location. When dealing with small, oddly shaped cells, however, or when trying to map signals and propagation characteristics within a complex area such as an "urban canyon", accuracy on the order of a few metres in three dimensions may be required.

91. In the future, many information services may require "time-of-day" information to a much higher degree of accuracy than is typical of services today. Universal personal communications services and broadband integrated services digital networks may require this in order to interface with several different types of communications systems to transmit tremendous amounts of digitally packeted information. Timing accuracies of 100 to 300 nanoseconds relative to UTC will probably be needed.

J. Spacecraft uses of the Global Positioning System

92. The application of GPS to spacecraft navigation and control, with its potential for saving spacecraft costs and mission operations, is being introduced into both government and commercial spacecraft systems. GPS is currently being tested or used for several spacecraft applications, including orbit determination, attitude determination, launch and re-entry vehicle positioning and trajectory determination, as well as time synchronization.

93. The use of GPS for real-time determination of orbital parameters provides an economical means of very accurately determining the orbit of a spacecraft. A properly designed, space-qualified GPS receiver can replace several conventional orbital positioning spacecraft sensors, reducing both weight and cost, and in some cases relieving the requirement for worldwide, ground-based stations to track orbital positions. In addition, the orbital parameters determined with GPS can in some cases be input to an on-board control computer and propulsion system to provide autonomous station-keeping. That would remove or reduce the need for mission operations personnel to control the orbital position of a spacecraft from the ground.

94. In recent years, several manufacturers of GPS receivers have started collaborating with spacecraft developers to design GPS receivers for use as attitude sensors on board spacecraft. On-board attitude determination is a requirement for virtually every modern spacecraft, and most also require an automatic attitude-control system. The traditional suite of sensors used for attitude determination range from relatively low-cost magnetometers and horizon sensors to precise gyroscopes, Sun sensors and star trackers. GPS may provide a cost-effective complement or even an alternative to many of those existing systems.

95. GPS also has applications to space launch vehicles as a sensor in the vehicle navigation system and in providing positioning information to ground controllers for range safety purposes. Most range safety tracking for launch vehicles is currently conducted using a rather elaborate and expensive system of ground tracking radars and associated equipment. GPS-derived trajectory data could be more cost-effective.

K. Mineral prospecting

96. GPS is now extensively used in airborne mineral prospecting, making aerial surveys at an altitude of 100 metres or less and with a close spacing of a few dozen metres between successive flights, using highly sophisticated electromagnetic, magnetic and gravity measurement techniques. Accurate position determination of the flight path is required to assess the magnitude, depth and location of the mineral deposits along the track extension.

L. Public safety

97. GPS used in conjunction with communications links and computers can provide the backbone for systems tailored to applications in urban delivery, public safety and vessel and vehicle tracking. Therefore, police, ambulance and fire departments are adopting GPS systems to pinpoint both the location of emergencies and the location of the nearest response vehicle on a computer map. With such a clear visual picture of the situation, dispatchers can react immediately and confidently. GPS is helping to save human lives.

V. ECONOMIC AND SOCIETAL BENEFITS

A. Needs

98. The world community should play an active role in satellite navigation and position services by participating in the development and exploitation of a global system that answers the needs of all civil users. The reasons for this are threefold:

(a) *Social and economic*. The potential market of the navigation signal is enormous and, even if air transport is currently generating most of the interest in satellite navigation, other sectors, in particular road transport, traffic management and agriculture, will account for most of the revenue in the short to medium term. The advantages of a global satellite navigation system include simplification through the use of a single system that could meet all user requirements and operate worldwide 24 hours a day. A space-based system will also provide improved accuracy of position and velocity measurements, which will lead in turn to a reduction of waiting times, fuel savings, better environmental protection and a reduction in the number of accidents;

(b) *Industrial*. Since satellites have only a limited lifetime, space segments must be continuously maintained and updated. Ground segments must be extended to provide greater geographical coverage and improved services. Both must be supplied by industry. New services stemming from the use of the navigation signal include transportation applications, precision agriculture, public safety, geosciences and recreational activities. The market for GPS receivers, currently evaluated at over $2 billion, will increase to between $8 billion and $9 billion in 2000, and to $50 billion in 2005. The applications share is expected to be 92 per cent for terrestrial (mainly car navigation and consumer/cellular applications), 4.5 per cent for aeronautical, 2 per cent for maritime, and 1.5 per cent for military applications;

(c) *Regulatory*. Certification of a space system poses new challenges to regulators, especially those responsible for services concerned with the safety of life. The relevant authorities must decide on their certification policy for future GNSS.

B. Promotion of international cooperation

99. Satellite navigation lends itself by nature to regional and global cooperation. Indeed, a large degree of cooperation is essential if a seamless multimodal satellite-based radio navigation and positioning system is to

be achieved throughout the world. The transition from various ground and space-based systems to a common satellite-based navigation system will require a great deal of cooperation between international civil authorities, Governments and industry representatives.

100. Possible schemes for GNSS-2 development include: an independent development of a worldwide system by a single country or entity (as is the case today); joint development with some or all the major players (India, Japan, Russian Federation, United States and European Union), or independent development of several interoperable regional systems, with the potential to grow into a global system. Many States have an interest in the development of GNSS technologies. In an effort to expand GPS benefits internationally and progress towards the implementation of GNSS, some organizations have been very active in assisting others with the implementation of GPS and its respective augmentations.

101. Fitting both GPS and GLONASS into current (and in the future GNSS) worldwide application developments will require considerable skill and coordination. Member States are beginning to see benefits from the augmentation of GPS and are taking the appropriate actions to develop a similar capability, nationally or regionally.

C. Issues and concerns

102. In the coming years, the international community must work together if a worldwide seamless navigation system based on GPS/GLONASS augmentation is to become a reality. In the longer term, new frameworks for legislation, regulations, certification, standardization and cost recovery will be needed.

103. It is likely that international organizations, as well as individual nations, would like to keep an independent oversight of the GPS augmentations which they have implemented. This oversight may be accommodated in international or regional agreements.

104. Although the benefits of satellite navigation are well understood and accepted, there is a concern that not all classes of users (aviation, maritime, road vehicles, railways etc.) may be able to inject their requirements into the design of a second-generation system. Another major concern is how the cost of building and operating the system could be split on a fair basis between the different users.

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SPACE COMMUNICATIONS AND APPLICATIONS

Background paper 5

The full list of the background papers:

1. The Earth and its environment in space
2. Disaster prediction, warning and mitigation
3. Management of Earth resources
4. Satellite navigation and location systems
5. Space communications and applications
6. Basic space science and microgravity research and their benefits
7. Commercial aspects of space exploration, including spin-off benefits
8. Information systems for research and applications
9. Small satellite missions
10. Education and training in space science and technology
11. Economic and societal benefits
12. Promotion of international cooperation

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PREFACE

The General Assembly, in its resolution 52/56, agreed that the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III) should be convened at the United Nations Office at Vienna from 19 to 30 July 1999 as a special session of the Committee on the Peaceful Uses of Outer Space, open to all Member States of the United Nations.

The primary objectives of UNISPACE III will be:

(a) To promote effective means of using space technology to assist in the solution of problems of regional or global significance;

(b) To strengthen the capabilities of Member States, in particular developing countries, to use the applications of space research for economic and cultural development.

Other objectives of UNISPACE III will be as follows:

(a) To provide developing countries with opportunities to define their needs for space applications for development purposes;

(b) To consider ways of expediting the use of space applications by Member States to promote sustainable development;

(c) To address the various issues related to education, training and technical assistance in space science and technology;

(d) To provide a valuable forum for a critical evaluation of space activities and to increase awareness among the general public regarding the benefits of space technology;

(e) To strengthen international cooperation in the development and use of space technology and applications.

As one of the preparatory activities for UNISPACE III, the Office for Outer Space Affairs of the Secretariat has prepared a number of background papers to provide Member States participating in the Conference, as well as in the regional preparatory meetings, with information on the latest status and trends in the use of space-related technologies. These papers have been prepared on the basis of input provided by international organizations, space agencies and experts from all over the world. A set of 12 complementary background papers have been published and should be read collectively.

Member States, international organizations and space industry planning to attend UNISPACE III should consider the contents of the present paper, particularly in deciding on the composition of their delegation and in formulating contributions to the work of the Conference.

In the preparation of this background paper, contributions from the following organizations have been used: African Advanced Level Telecommunications Institute (AFRALTI); European Space Agency; Indian Space Research Organization; International Telecommunication Union; Department of Space of the Government of India; International Telecommunications Satellite Organization (INTELSAT); National Institute of Aeronautics and Space (LAPAN) of Indonesia; National Aeronautics and Space Administration (NASA) of the United States of America; Russian Scientific Research Institute of Radio (NIIR); Satel Conseil; and World Meteorological Organization.

The assistance of M. J. Rycroft (International Space University, Strasbourg, France and Cambridge University, United Kingdom of Great Britain and Northern Ireland) as technical editor of background papers 1-10 (A/CONF.184/BP/1-10) is gratefully acknowledged.

SUMMARY

The present paper gives an overview of satellite communications technologies and future trends in that field. The convergence of telecommunications and information technology, evidenced by the development of the Internet, has been accompanied by a convergence of fixed and mobile communications services. This is happening at a time of growing globalization of telecommunications and increasing demand for services including transmission of data, sound and images, both in fixed and in mobile networks. The reduction of all types of information and communications to a digital format has broken down the barriers that once separated those market sectors.

Trends in satellite communications reflect a shift towards more geographically extensive and flexible mobile services, as well as a move towards more broadband services. The field of satellite communications is also moving towards market integration and the removal of barriers that once divided the various information and telecommunications services and products.

Satellite communications is in a period of dramatic change. Competitive pressure from terrestrial technologies is placing new demands on the satellite industry. From a technological point of view, today most satellite services are digitally provided or are converting quickly to that mode of operation. The trend towards smaller and more user-friendly terminals is continuing.

Geostationary technology is in full development; selecting multi-spot access or access on demand is becoming a realistic choice. The demand for high-powered direct broadcast satellites with broad coverage patterns will sustain the geostationary satellite market. However, the demand for improved look angles, increased frequency reuse and lower path losses for mobile satellite services will encourage the rapid deployment of low-Earth orbit (LEO) and medium-Earth orbit (MEO) satellite systems for expanding the land-mobile satellite market.

Satellite-based personal communications service systems from a global LEO satellite constellation will soon offer voice, low-rate data and facsimile services to small, inexpensive terminals. The technologies are less capital-intensive and better adapted for use in remote regions and sparsely populated areas than earlier communications systems.

For advanced broadband multimedia services, satellite systems with very high capacities allow for high-rate direct user access, with interactive low-cost user terminals. The systems, which will be launched early in the twenty-first century, are expected to play an important role leading to advanced Internet access.

The economic growth of the developing regions could be significantly accelerated or facilitated by affordable telecommunications services. Broadband satellite services, at affordable costs, are ideally placed to allow those regions to immediately acquire modern infrastructure.

I. TELECOMMUNICATIONS MARKETS EARLY IN THE TWENTY-FIRST CENTURY

A. Current situation

1. The current telecommunications situation may be illustrated by the following figures: the 24 most developed countries account for 70 per cent of global telephone mainlines, 80 per cent of service revenues and 90 per cent of mobile phone subscribers, even though they account for only 16 per cent of the world's population; at the other extreme, 80 per cent of the world's households do not have telephones.

2. Access to inexpensive communications bandwidth will be an essential factor for economic development in the twenty-first century, just as inexpensive power was for the Industrial Revolution. Developing market countries must be assured of ample, low-cost access to high-density broadband telecommunications links.

3. It has been estimated that 25 years and at least US$ 1 million million would be needed to connect the globe with fibre optics. Other experts estimate that the total cost of closing the telecommunications gap, only in developing countries, could be as high as US$ 3 million million, as less than one fifth of the world's land surface is wired for communications services. Even though there are many fibre-optic networks in the world and their numbers are growing each day, they are used primarily to connect countries and central offices of telephone companies with high-density traffic by trunk lines. Connecting fibre cables (materials and labour) to individual offices and households represents 80 per cent of the cost of a network. Many experts believe that, in most of the world, fibre-optic cables will not solve the problem completely.

B. Convergence of telecommunications and information technology

4. Over the next decade, the worldwide telecommunications industry and, in general, the information technology industry, will undergo massive changes. Privatization of governmental telecommunications sectors and deregulation are the driving forces of the infrastructure development and restructuring in the industry.

5. The information industry has traditionally been defined in terms of the "form" of information and the underlying technologies for handling each type of information, including image, text, voice, data, audio and video. Each form must perform a series of functions, including creation, distribution, process, storage and display, to serve its markets.

6. The primary force behind the convergence of these different forms of information is technological change, and the key change has been the rapid diffusion of digital technology into an ever-wider array of information businesses. In addition to digitization, dramatic changes in the computing and telecommunications industries are also causing the convergence.

7. Digital technology will enable interactive multimedia and video information to come into every household in various ways: through the air via satellites and terrestrial wireless systems, through fibre-optic cables and cable television and even through telephone lines.

8. Telecommunications will be the driving force behind progress and development in the beginning of the coming millennium. The rate of growth of communications infrastructure and services is exponential, fed by commercial economic forces that follow the deregulation process in many countries. However, this activity threatens to widen the gap between the developed and the underdeveloped countries, which is undesirable to both.

C. Transmission technology trends

9. Communications satellites are particularly attractive, as they provide access for narrowband through broadband services, allowing for immediate access to information resources anywhere in the world; for that reason, they will become even more attractive in the future. They can provide the required transmission bandwidth, in particular high-speed links, on demand, and they allow service providers to offer their services independently of any other network infrastructure. For example, for their communication needs, interactive services will require a number of different access rates, comprising narrowband services (up to 64 kilobits per second (kbps)) and going up to broadband services in excess of 2 megabits per second (Mbps).

10. The most important application is voice transmission. Virtually all voice transmission over satellite links is now done using digitized voice signals. The analog speech is passed through a voice encoder-decoder where pulse code modulation (PCM) encoding is carried out at the rate of 64 kbps. This is known as "toll quality" because it is the encoding standard used by major long-distance carriers for their digital networks. It provides for excellent speech reproduction, but it also consumes a significant amount of bandwidth. To conserve bandwidth, voice encoders that provide good-quality and acceptable-quality speech at 32, 16 or even 8 kbps are widely used in satellite communications networks.

11. In the future, utilization of spread spectrum technology integrated with code division multiple access (CDMA) technology will thrive significantly, because the encoding characteristics are able to provide services to a larger number of consumers. Besides, this integrated technology also provides better quality and safety of transmission. In terms of possible jamming, the signals transmitted are more reliable; multipath signals and the probability of their interception are very low, so unauthorized access to the data transmitted can be precluded.

12. Based on bandwidth requirements, today's applications can be grouped into three categories:

(a) Narrowband (up to 64 kbps) for voice transmission, interactive data, audio entertainment, image, facsimile, electronic mail (e-mail), Internet;

(b) Wideband (from 64 kbps to 1.544/2.048 Mbps) for voice/data networking, interactive library, business television, video entertainment, e-mail, Internet;

(c) Broadband (above 1.544/2.048 Mbps) for voice/data trunking, high-definition television (HDTV).

D. Trends in digital consumer products in the United States of America

13. Judging from current technology trends, it is apparent that computers will be operating 1,000 times faster by the year 2010. Today, in the United States of America, the country with the most developed information-related services, more people are building computers than building cars, more people are making semiconductors than producing machinery and more are working in data processing than in petroleum refining. United States information technology companies generate over 3.5 million domestic jobs. In 1996, United States shipments of computer hardware, telecommunications equipment and electronic components were valued at US$ 166.4 billion. Computer software alone is the third largest manufacturing industry in the United States economy, accounting for US$ 66.8 billion. More than 2.7 million million e-mail messages were sent in the United States in 1997.

E. Internet

14. The World Wide Web is growing at the astonishing rate of more than 300,000 pages of data, pictures, sound and text each week. If the number of Internet users were to continue to grow at recent rates, the population of the entire world would be using the Internet by the year 2004. However, telecommunications companies expect that no more than 20-30 per cent of the population in developed countries will become Internet users.

15. In January 1998, some 20 million hosts provided services to around 100 million users around the world; however, the number of Internet users worldwide is still small compared to the number of telephone lines, which was calculated at around 750 million in 1997. It is estimated that the value of goods and services traded over the Internet will reach US$ 327 billion within the next five years. Some 100,000 new Internet and multimedia jobs were created in 1997.

16. The real future for mass market use of the Internet may finally rest not on the increasing use of personal computers and telephones but on a model closer to that of television broadcasting. Today, the average person in the United States spends less than 3 hours per year connected to the Internet and some 1,500 hours per year watching television.

17. The Internet is displacing traditional computer networks and showing the first signs of how it may provide a platform that eventually may replace traditional methods of trading. For example, traditional business-to-business trading on closed corporate networks is giving way to multidimensional commerce on global open networks. The Internet is also providing an alternative means of offering the core telecommunications business activity (even if differences in quality still distinguish the two services) through the delivery of Internet telephony, in some cases without either party needing to have a computer. The Internet

is also a significant platform for broadcasting services. For example, today, there are more than 650 Webcast radio stations and 270 "real-video" enabled sites on the Internet, offering video material of current European and United States broadcasters.

18. New Internet techniques, such as multicasting, offer the possibility of delivering audio and visual content to up to 50,000 users at any one time instead of 50,000 individual messages, narrowing the borderlines between previously separate sectors. Many experts consider that the Internet will become a major conduit for video and sound (especially music) distribution.

II. CURRENT SITUATION WITH TRADITIONAL COMMUNICATIONS SATELLITE SERVICES

A. Overview

19. When satellite communications were introduced in the 1960s, it was considered advantageous for international communications. The phenomenal developments in satellite communications over the past three decades have led to the establishment of a large number of regional and domestic systems, including those of several developing countries, providing a host of telecommunications and broadcasting services.

20. Satellite communications is the key technology that could bring developing countries to participate in the build-up of the Global Information Infrastructure (GII). Satellite communications systems, featured by large "footprints" (coverage), ranging in size from a country to a continent, avoid the need for terrestrial infrastructure and shorten the time for establishing basic and advanced communications in rural areas. While developing countries do not constitute a major market for most of the large-scale satellite communications projects, they benefit from the economically lucrative markets in developed countries that lure commercial international programmes and may use the excess capacity in those programmes to satisfy their own communications needs.

21. Satellite systems have important features that fibre optics lack: (a) mobility (mobile users cannot be connected to the fibre network directly); (b) flexibility (once terrestrial infrastructure is built, it is extremely expensive to restructure it); (c) rural and remote connections (it is still not cost-effective to deploy high-capacity fibre networks in areas with low-density traffic and difficult topography); and (d) broadcast (point-to-multi-point) capability (reaching millions simultaneously in a cost-effective way). Thus, satellites and wireless technologies will be important in the future implementation of GII.

22. New satellite communications technology could intervene, in particular, in rural, low-density traffic areas. Rural customers now cost between 10 and 30 times as much to serve with telephone wires as urban customers do. Developing countries have only 1-3 per cent of the number of telephones that developed countries have and only 10 per cent of the number of television sets. Some 3 billion people, about one half of the world's population, live in countries with less than one telephone line per 100 inhabitants. Recent research indicates that wireless systems are the most cost-effective way to develop or upgrade telecommunications networks in many areas where the user density is lower than 200 subscribers per square kilometre. Fixed wireless systems can be installed 5-10 times faster than wireline networks (which require considerable investment in infrastructure) and initial costs are comparatively small. A number of countries have been turning to wireless access to meet the urgent demand. In countries with underdeveloped telecommunications infrastructure, the wireless segment could represent 50 per cent of the local telephone market within the next 10 years.

23. Until recently, satellite investments represented only 1-3 per cent of the investments for terrestrial communications networks. Annual expenditure for satellite and launch vehicles has grown to US$ 8 billion per year, nearly 6 per cent of the capital investment for telecommunications. More satellites are expected to be launched in the next 10 years than have been put into orbit for the past 30 years. Nearly 800 of the 1,138 satellites projected over the next 10 years will be for mobile communications systems. During the last five years, the worldwide growth rates for mobile telephony have hovered at an astonishing 50 per cent per annum, and at present some countries are actually doubling their mobile subscriber base every year.

24. Market research that provided figures for the future satellite market estimated the spending on GSO satellites for the period 1996-2006 to be between US$ 23 billion and US$ 29 billion. Another market analysis predicted that 273 commercial satellites, with a value of US$ 37.8 billion, would be launched in the period 1997-2006, representing an increase of 27 per cent over a market forecast done one year earlier; the newly added satellites would be mostly broadband and multimedia Ka-band satellites.

25. The worldwide growth of satellite communications, combined with new services requiring expanded bandwidth and the capability to operate in nearly every country almost immediately, will result in the tripling of direct satellite revenues for those services, to an estimated US$ 29 billion, by the year 2000. It is expected that the World Trade Organization agreement negotiated early in 1997 will increase international telephony traffic by 80 per cent. Satellite providers could capture a significant portion of the market demand in rapidly deregulated environments.

26. Satellite communications consists of the space segment (satellites, launchers, control stations and the related space insurance sector), the ground segment (end-user terminals and networks) and the services provided. With the expansion of direct-to-home (DTH) television and digital audio broadcasting (DAB) services and the introduction of personal communications and multimedia services, the ground segment will grow by millions of users per year and its worldwide market will amount to nearly twice that of the space segment. But the service segment will represent by far the biggest segment. The total market for the coming 10-year period is estimated to be between US$ 60 billion and US$ 80 billion for the space segment, between US$ 120 billion and US$ 150 billion for the ground segment and over US$ 400 billion for services. This will amount to a global market for satellite communications with a total value of over US$ 600 billion.

27. The international satellite organizations, the International Telecommunication Satellite Organization (INTELSAT), the International Mobile Satellite Organization (Inmarsat) and the European Telecommunications Satellite Organization (EUTELSAT), have been of major importance to the development of satellite communications over the last few decades. As they face increased competition in large parts of the world, the international satellite organizations are discussing their future role and structure in the context of their evolution from their current status as intergovernmental organizations.

28. Global satellite systems such as INTELSAT function as universal common carriers of traffic between major land masses and/or individual countries, providing connections between various domestic terrestrial networks and allowing the orderly systematic flow of voice such as telephony, data and video traffic beyond boundaries. The fixed satellite service (FSS), exemplified by INTELSAT, has been the most successful service of commercial satellite communications.

29. More than two thirds of INTELSAT members and users are developing countries. Throughout its history, INTELSAT has pursued policies and programmes to enable all nations to realize the benefits of satellite communications. Developing countries that are members and users of the INTELSAT system will also be able to achieve the full potential of GII. Future service development and technology programmes of INTELSAT will continue to take into account the fast-paced technological and market developments in the following service or technology areas: Internet service, video, personal communications, Ka-band multimedia services and voice/data service for the public switched network. The new INTELSAT satellites under procurement will expand the range of present system architectures, add new flexibility to the global network and provide innovative spacecraft options that will diversify INTELSAT service offerings in the coming years. In addition, members and users of INTELSAT may avail themselves of its special programmes that provide experience and training in the management and operation of satellite communications systems and a full range of technical, operational and financial assistance.

B. International Telecommunication Union activities

30. Unfortunately, the radiofrequency spectrum is a finite resource. The equitable distribution of this resource, as well as the development of new ways of increasing the "spectrum efficiency" of radiocommunications services—that is, the ability to deliver the same service using less spectrum or to share spectrum with other services without causing interference—is one of the most important tasks of ITU.

31. ITU plays an important role in the planning, coordination and implementation of satellite-based systems for communications and scientific applications. As the international body responsible for the management of the radio frequency spectrum/geostationary satellite orbit resource, ITU has seen its role grow as new systems for communications and scientific applications are conceived and developed. With satellite-based communications moving into an era of personal communications by satellite, ITU has also been called upon to provide a forum for the discussion of telecommunications policy associated with those developments and to develop guidelines for their implementation.

32. The pressure on the spectrum/orbit resource, caused by the increasing demands for access to it resulting from these new communications developments, led to a fundamental review of the ITU planning and coordination framework for satellite systems. The review resulted in some important decisions being taken at the World Radiocommunication Conference held at Geneva from 27 October to 21 November 1997.

C. Fixed satellite communications

33. Today, international, regional and domestic satellite systems are predominantly for "fixed services" (i.e. non-mobile Earth stations). These satellites represent 90 per cent of the commercial systems in operation, and almost all of them operate in the C-band (6/4 GHz) and the Ku-band (14/12 GHz). The 30-year trend in FSS has witnessed the development of increasingly more powerful communications satellites, moving from spin-stabilized to three-axis stabilized satellites having higher-gain and larger-aperture antennas, operating with multi-beams to achieve multiple frequency reuse.

34. These trends have not only enabled the satellites to increase their capacity and lifetime but have also allowed operation with much smaller and cheaper ground stations. The remarkably rapid growth in FSS satellite technology has kept pace with competition from fibre-optic cables and the rapidly growing demand for international telecommunications traffic and all forms of television relay. The desire to decentralize Earth station facilities and to reduce their costs has also been a key factor in the marketplace.

35. Satellite transmissions are more costly than terrestrial wireless transmissions. At present, a twisted pair of wires can support 56 kbps into a home for about US$ 25 per month. Satellites currently provide 9.5 per cent of the international telephony circuits, but the space-based share of this market is falling. Except for video haul, satellites have a relatively small transmission market share. Still, there are more than 170 operational communications satellites in GSO for FSS. Furthermore, at the end of 1996, over 100 FSS satellites were under contract and 150-200 additional FSS satellites were in the planning stage.

D. Satellite television and radio broadcasting

36. Although nearly 100 per cent of the broadcasting industry employs satellite technology, broadcasting only comprises approximately 30 per cent of the overall traffic of communications satellites. While the need for satellites in the broadcasting industry is unquestionable, satellite operators are finding that it is no longer acceptable just to provide the technological link.

37. By 1995, 6 per cent of households with televisions worldwide and 9.8 per cent of such households in high-income countries received satellite transmissions. At the same time, 23.6 per cent of such households worldwide and 41.7 per cent of such households in high-income countries had cable television subscriptions. At the end of 1996, there were over 1,500 transponders (36 MHz equivalent) worldwide for television relay. For 1997, the number of television broadcasting transponders is estimated to reach 3,350. That figure is expected to continue

to increase for several years. Direct broadcasting satellites (DBS) provide about 15 per cent of the transponder capacity (400 transponders) today, but the fraction is growing with additional launches.

38. DTH broadcasting is expected to meet the needs of more than 800 million households with television worldwide and of more than 2 billion people currently without access to television. The DTH market is comprised of three segments: the traditional market, served by C-band and large antennas; the new DBS, typically served by Ku-band and antennas of less than 1 metre; and the emerging satellite-based DAB. The total DTH market was estimated to be US$ 3.9 billion in 1996, with the subscriber base growing at 37 per cent per year.

39. Radio is the most ubiquitous communications medium in the world. There are over 2 billion radio sets in the world and over 100 million sets are sold every year. In developing countries, for example, on average, there is one radio station for every 2 million people; in developed countries, there is one station for every 30,000 people.

40. WorldSpace Inc., whose goal is to bring cheap but high-quality digital radio broadcasting to 3.5 billion people, relies on a DAB system that works by routing a radio signal through a very small aperture terminal (VSAT) (see paragraphs 44-52 below) up to a geostationary satellite. The satellite transmits down the signal, which is picked up by millions of portable radio receivers. The new global infrastructure that WorldSpace is creating will enable broadcasters and advertisers to reach underserved, emerging markets in, for example, Africa, Asia, the Caribbean, Latin America and the Middle East. People in those areas will be able to receive digital sound broadcasting of unprecedented quality and diversity on a new type of radio needed to receive programmes from WorldSpace satellites.

41. There are three satellites, each weighing around 3,000 kg, AfriStar, AsiaStar and CaribStar. All three will be in GSO. Each satellite has three spot beams, each one representing a coverage area of approximately 14 million square kilometres for a single channel. It will be possible to broadcast up to 288 channels for talk radio, 144 for monophonic music or 72 for high-fidelity sound.

42. The portable WorldSpace receiver uses several technologies to achieve the objectives of low cost, small size and good reliability. The receiver consists of the antenna, Starman chipset, audio amplifier, speakers, monitor and serial interface. The radios will receive high-quality monophonic and stereophonic radio programmes close to compact disc (CD) standards, transmitted in L-band (from 1,467 to 1,492 MHz) via the three communications satellites of WorldSpace. The use of digital transmission technology allows other services to be offered, including text, facsimile, e-mail and message-paging services. A business-card-sized antenna inside the receiver will receive the satellite signals. In addition, the receivers will be equipped for standard amplitude modulation (AM), frequency modulation (FM) and short-wave broadcasts. The primary unknown remaining on the financial and technical side is the price of the portable radios. The initial price is estimated at about US$ 200, out of reach of all but the middle classes in developing countries but still low enough to attract between 5 million and 10 million listeners, in order to break even.

43. Some countries are also planning experimental and operational domestic satellite sound broadcast services in the 2.5 and 2.3 GHz bands.

E. Very small aperture terminal networks

44. VSATs are proven technology for wide-area networking. They are designed for asymmetric traffic, are capable of broadcasting simultaneously to multiple users and are fully compatible with the Transfer Control Protocol/Internet Protocol (TCP/IP). Generally, VSAT system design reduces to a minimum the amount of satellite capacity used while meeting the user's performance requirements. This has resulted in different VSAT architectures that are optimized for data, voice or video applications.

45. VSATs are probably the most successful networking technology that satellites provide. VSAT industry revenue has grown from US$ 200 million to US$ 800 million in 10 years of operations. Growth is expected to

continue and possibly accelerate with the planned introduction of "interactive", two-way mesh VSAT networks. However, the success of VSATs pales when compared with that of traditional telephones, cellular phones and the Internet. The cellular market share accounts for 20 per cent of the telephone lines while the VSAT share is insignificant.

46. Typical Ku-band VSAT terminals are 1.0-1.2 m in diameter. These systems provide data access at a rate of 64 kbps-13.5 Mbps for business customers. Monthly service rates are on the order of US$ 150-300 per month, including lease of the terminals. Capital investment for the terminals was initially US$ 15,000 per installation but has dropped to US$ 4,000. Currently, however, the total number of terminals worldwide is around 250,000. In a mass market, production costs would drop. Based on experience in other mass market technologies, a cost of US$ 1,000 per terminal is within reach if the production volume increases to millions.

47. A new architecture for VSAT networks has been developed to give users a more efficient way to transmit both data and voice. This is known as a hybrid VSAT because it combines two common VSAT architectures in a single platform. Users who require both interactive data and voice applications can use hybrid networks to achieve the best performance for both applications.

48. VSAT designers continue to enhance the performance of their products. On the VSAT market the main trend has been the introduction of the demand assignment multiple access (DAMA) protocol, which is a demand-assigned bandwidth that enables the use of multiple applications on VSAT networks without double hop. Upgrading the system to DAMA is still costly, but the protocol is ideal for voice, video and data communications.

49. VSAT rural telephony products use existing satellites and apparently are more cost-effective than alternatives such as planned LEO/MEO and geostationary satellite mobile phone systems. Some VSAT products estimate a cost per minute of US$ 0.05-0.15 versus US$ 3 for some LEO systems. Equipment costs are also 10-30 per cent of those for future mobile satellite systems. There is also a big market for VSAT-based paging services. However, the new VSAT applications, especially rural telephony, have been slow in their development. VSATs will allow communities to connect to a hub station or directly to international networks, giving instant access to both basic telephony and more advanced applications, ranging from simple Internet to full multimedia applications such as telemedicine and distance education.

50. In Africa, the leading country in VSAT usage is South Africa, with more than 2,000 VSAT sites currently deployed for all kinds of applications and more and more for rural telephony. Communication service providers throughout Africa are turning to VSATs to improve their rural links. The combination of VSATs, DAMA and wireless local loop technology promises to improve dramatically rural access to telecommunications in a way that has not yet been possible. Interest in VSAT applications definitely exists both in Africa and in the Middle East. Standing in the way are government regulations, political strife and economic instability.

51. With over 20,000 VSAT terminals in operation, Asia accounts for 8 per cent of the global VSAT market. In India alone, over 5,000 VSATs are in usage and the demand for VSATs is practically doubling every two years. The combination of VSATs, DAMA and wireless loop transmission has been accepted as one of the important services for improving the rural communications infrastructure. In urban areas, the interconnection of local area networks with wide area networks and metropolitan area networks is taking place at a very fast rate to meet the growing demands of commercial establishments, public sector undertakings, electricity boards, banking establishments and the stock market.

52. With 24,000 terminals installed, Latin America accounts for 10 per cent of the world's VSAT market. Despite differences in the Latin American markets, there are four common conditions that are boosting VSAT sales. The first is geography: Latin America encompasses a number of countries with truly rugged terrain. The second is the regional and/or international scope of many Latin American businesses. The third is the improving economy. And the fourth is a deficit in telecommunications, with Internet hosts and personal computer users in the region doubling practically every six months. There is also demand for VSAT-based paging services.

Without a doubt, data dominate VSAT applications in Latin America; however, applications such as those used in the banking and the retail and automobile industries often include a voice element.

F. New communications satellite services

53. Satellite communications were introduced for the first time in the mid-1960s. There was considerable debate about the best orbits to be used for satellite services. The overwhelming choice at the time was GEO because Earth stations would not need to track a geostationary satellite. The cost and complexity of the ground segment was the dominant consideration. The orbit debate was not raised again until technology had advanced to the point where hand-held satellite telephones could be considered. By 1990, the designs for mobile satellite user terminals had antennas with omnidirectional or hemispherical coverage that could communicate with moving satellites without advanced knowledge of the satellite location.

54. New proposed services via satellite include voice, data, video, imaging, teleconferencing, interactive video, television broadcasting, multimedia, Internet, messaging and trunking. A wide range of applications is planned through these services, including distance learning, corporate training, collaborative work groups, telecommuting, telemedicine, wireless backbone interconnection (i.e. wireless local area network/wide area network), video distribution, DTH video and satellite news-gathering, as well as the distribution of software, music, scientific data and global financial and weather information. Satellite-based systems are also indispensable for emergency communications services.

55. According to ITU recommendations, these services have been classified into five categories: (a) messaging (electronic mailbox, paging); (b) retrieval (videotext, document retrieval, high-resolution image retrieval, data retrieval); (c) conversational (broadband person-to-person telephony, broadband multi-point videoconferencing, video surveillance, multiple-sound programme signals, high-speed unrestricted digital information transmission, file transfer, high-speed tele-action, facsimile, high-resolution image retrieval, document communication, digital telephony etc.); (d) user-controlled distribution (restricted digital information transmission, videography); and (e) interactive diffusion (message diffusion, voice and sound diffusion, document diffusion, unrestricted digital information transmission). Some of these services include the following:

(a) *Data transmission*. Satellites also provide paging and messaging services. The largest space-based data network has sold 175,000 terminals. The service is operated by Omnitracs, Euteltracs and related systems around the world. The system has been in operation since 1987, but a number of other space-based systems, including the Little LEOs (see paragraphs 70-77 below), are entering the business. The total market share for space-based messaging services is 0.31 per cent of the terrestrial paging business;

(b) *Near video-on-demand*. The availability of substantial transmission capacity at reasonable prices will soon make "near video-on-demand" services possible;

(c) *Pay-per-view*. Similarly, it is possible to market specific events or movie showings on an individual subscription. The greater capacity of digital television makes it possible to broadcast simultaneously several such events, giving viewers the choice of access to a particular event on a "pay-per-view" basis.

56. These services, which represent significant departures from classic, schedule-based broadcasting, have the potential to improve consumer choice. In addition, because a "digital channel" is inherently more flexible than an analog channel, it can deliver other services in the form of data, graphics, moving pictures or combinations of these. Digital television shares these characteristics with DAB, which also offers listeners almost CD-quality sound. "Multimedia data broadcasting" already provides for the downloading of computer programs, including video games, data files and direct access to the Internet from the television set or network computer.

G. Digital video and audio broadcasting

57. In the early 1990s, it became apparent that digital technology could be used efficiently and cost-effectively for the delivery of television and audio signals. Of particular interest was the possibility of delivering many

more channels over the same infrastructure (cable television, satellite transponders, terrestrial spectrum) by using digital compression rather than existing analog transmission.

58. The arrival of digital radio offers exciting possibilities for the combination of radio and images, or links to Internet sites, marketing CDs or tickets and so on.

59. The digital DTH and broadcasting satellite service systems use compression, squeezing 5-10 video channels into a single 36 MHz transponder. In the past, only one or two channels occupied that bandwidth. Early in 1996, only about 30 per cent of television transponders were carrying digital signals with compression. It has been estimated that, by the year 2000, 2,700 of 4,100 C-band and Ku-band television transponders, some 66 per cent, will be digital, with compression ratios of 5 to 1. That means that the number of satellite television channels will increase from 2,400 in 1996 to 14,900 in the year 2000, an increase by a factor of more than six in four years. In Asia and the Pacific, for example, 400 C-band and 500 Ku-band transponders will be added between 1996 and 2001. With digital compression, 4,500 television channels could be added.

III. GLOBAL MOBILE PERSONAL COMMUNICATIONS BY SATELLITE

A. Overview of mobile communications

60. Today, users can remain in contact wherever they are. Mobile communications is no longer the privilege of the businessman or the traveller. They offer everyone the ability to make phone calls, receive facsimiles, check their e-mail or use the Internet while on the move. Mobile communications has become an essential tool for businesses of every size; however, it is also reaching an increasing number of homes and, as such, now has an important socio-economic function. For example, mobile communications may facilitate teleworking or people gaining access to their homes while on the move.

61. The part of the electromagnetic spectrum that can support radiocommunications (from around 9 kHz to 400 GHz, well below the frequency of visible light) has come to support a huge but still growing number of services. Mobile telephones, pagers, wireless computer networks, walkie-talkies, aircraft and maritime navigation equipment, meteorological and environmental monitoring systems, deep space research and, of course, television and radio broadcasting all use the radiocommunications spectrum to send and receive information.

62. The development of new and useful technologies, such as mobile telephony and mobile computing, satellite-based meteorological forecasting and improved positioning and safety systems for aircraft and shipping, as well as the growing market for DTH subscriber broadcasting and other consumer services, is stretching the capacity of the radio frequency spectrum to accommodate all the services already in place and planned for the near future.

63. Recent technological developments have enabled the development of a new type of satellite communications systems that is small, relatively cheap to manufacture and launch and capable of orbiting much closer to Earth. These new kinds of systems are generally known as global mobile personal communications by satellite (GMPCS), a term that encompasses a range of systems, some of them based on existing geostationary satellite technologies. They do have enormous potential to change the way in which the world communicates. At the moment, three major systems (Iridium, Globalstar and ICO) are in the advanced stage of implementation; all of these are expected to become fully operational by the year 2000. GMPCS is the first truly mobile communications system that will not only provide communications facilities to hand-held telephones on mobile platforms and extend the facilities to cellular users to roam beyond the cellular region, but will also be the low-cost method of rapidly implementing fixed or mobile services to rural areas not covered by regular telephony or cellular services.

64. The globalization of the world economy is the driving force behind the development of GMPCS. Increased personal mobility and the evolution of many businesses into large regional or even global operations are

profoundly changing the ways in which we communicate. The popularization of the facsimile machine and, later, the widespread growth of worldwide data networks have greatly increased the traffic on international routes and accelerated the pace of business operations.

65. To overcome the incompatible cellular standards and poor local line quality and to make people reachable by telephone virtually anywhere on the planet, engineers began to examine the possibility of implementing a new type of system, one that would use a number of small satellites to pick up and relay telephone calls between towns, countries and geographical regions. GMPCS represents the new wave of personal telephony, promising global mobile facsimile, messaging, data and even two-way voice and broadband multimedia, connectivity via small, hand-held phone sets, computer-mounted terminals or laptops. They are satellite systems—whether geostationary or non-geostationary, fixed or mobile, broadband or narrowband, global or regional—capable of providing telecommunications services directly to end-users from a constellation of satellites. Most systems are scheduled to begin operation within the next four years and will be able to offer services to people the world over.

66. To facilitate regional, global and transborder roaming, national authorities are invited to recognize type approval and marking procedures for GMPCS terminals, to continue to strive for a single procedure for type approval and to exempt GMPCS terminals from the requirement of individual licences when the essential criteria given in the arrangements are met.

67. GMPCS system operators or service providers will provide, upon request, to the competent national authorities implementing these arrangements, GMPCS data originating in or routed to the national territory. Traffic data to be provided will exclude any confidential customer information. They will also assist with measures intended to identify unauthorized traffic flows.

68. The arrangements call upon countries to reduce duties on GMPCS terminals placed on the market and to exempt from customs-related restrictions and fees GMPCS terminals used when visiting or transiting countries on a temporary basis. In this respect, work will be undertaken with national authorities and international customs bodies to ensure that GMPCS terminals are considered part of a traveller's personal effects.

69. At present, some satellite systems, such as Inmarsat, have already been providing some of these services to transportable and portable terminals. The total number of subscribers to mobile satellite services for voice transmission is about 70,000, accounting for only 0.13 per cent of the cellular market in 1996. The new generation of Big LEOs (see paragraphs 70-72 and 78-80 below) and geostationary satellite systems are being constructed to provide these services to hand-held terminals. The systems expect a customer base of between 20 million and 30 million, which could approach 1 per cent of the market for mobile voice services by 2005.

B. Non-geostationary satellite systems

70. The evolution from geostationary to LEO satellites has resulted in a number of proposed global satellite systems that can be grouped into three distinct types that can be best distinguished by reference to their terrestrial counterparts: Little LEOs, Big LEOs and broadband LEOs. Little LEOs are the equivalent of paging systems, Big LEOs provide the equivalent of cellular telephone services and broadband LEOs are similar to fibre-optic networks.

71. The term Little LEO was originally conceived to distinguish those systems that operate at below 1 GHz from Big LEO systems, which operate at above 1 GHz. The word "little" implies both the small size of the satellites and the relatively low cost of system implementation. Both Big and Little LEO systems will launch their satellite constellations into low-Earth orbit.

72. A principal distinction between the two main types of system is that Little LEO satellites will offer a range of low-speed text and data services, while Big LEO satellites will offer users global voice, facsimile and possibly broadband services.

C. Little low-Earth orbit systems

73. Little LEO satellites are generally small, with a volume of around 1 cubic metre and a mass of about 100 kg. Most projects currently in the development phase propose to use the satellites as either bent pipe systems, or as store-and-forward systems. The bent pipe system relays messages directly between users, while the store-and-forward approach means that a satellite receives information from a ground station, stores it in its on-board memory, continues on in its orbit and releases the information to the next appropriate ground station or user. Users will access the new Little LEO systems using small hand-held messaging units weighing less than 0.5 kg and incorporating a low-power omnidirectional antenna.

74. Little LEO services will cater to a range of markets. Messaging is expected to be a high-demand service; it will include e-mail, limited Internet access, two-way paging and facsimile. Remote data communications will also be an important area, especially for emergency services.

75. Other important niche markets will be tracking (for the transportation management market), environmental monitoring and supervisory control and data acquisition (SCADA), a system that provides remote monitoring of isolated facilities such as mines and oil refineries.

76. Little LEO systems can create a rural communications system that would ensure virtually instantaneous data transmission for the collection, analysis and dissemination of life-saving information on infectious diseases, facilitate medical diagnoses of complex cases remote from medical centres, provide near real-time safety and alarm monitoring in areas not otherwise served by telecommunications, provide early warning of hurricanes, earthquakes, volcano eruptions and other environmental and climatic disasters, and deliver educational information to schoolchildren in remote locations.

77. Little LEO systems are digital data services that enhance, not replace, existing services, thereby avoiding bypass issues. Using the above example of rural communications, Little LEO services can extend the reach of public services for mere cents per minute beyond areas served by terrestrial infrastructure. Regional or national service providers will keep a substantial amount of the revenue.

D. Big low-Earth orbit systems

78. The Big LEOs promise users a greater range of services. The best known of these is global mobile telephony—the ability to make and receive calls on a mobile telephone anywhere in the world. Other services will include data and facsimile. The main contenders will offer hand-held mobile terminals that are only a little larger than today's diminutive cellular phones, although they incorporate a larger aerial.

79. The Big LEO systems will comprise a constellation of many satellites, moving around the globe and picking up and relaying users' telephone calls from one country region, or continent to another. Some of the proposed systems support satellite-to-satellite communications, making them, in reality, an enormous wide area network. Most rely on uplinks and downlinks to Earth stations to complete the call circuit and will use existing terrestrial infrastructure whenever possible.

80. The advantages of the Big LEO systems are obvious; however, the cost must also be considered. Compared with the Little LEOs, the cost of a call using a Big LEO system, at least initially, will probably be prohibitive for most users, with the exception of large corporations with a genuine need for instant global voice communications to remote areas at any time. Those users simply needing a global voice network or a global high-speed computer network can in many instances already meet their needs with existing fibre-optic networks or with the kinds of value-added networking services now being offered by most of the leading telecommunications carriers. Furthermore, some systems in GSO, such as the system operated by Inmarsat, can already provide similar voice and data services from traditional types of telecommunications satellites.

E. Broadband systems

81. With the enormous growth in personal communications, Internet, data transfer, DTH television and even basic voice communications, the demands being placed on the radio spectrum and GSO are leading to ever more creative ways of exploiting them and to the opening up of higher frequencies, including the Ka-band, which until now has not been used much. The growing congestion in the traditional frequency bands used by satellite systems for the provision of global international services coupled with the new communications service offerings and the rapid developments in technology led to new systems using the 30/20 GHz bands being planned.

82. The new proposed satellite (operating in the Ka-band) and stratospheric (operating in the V-band) systems would accelerate the realization of both the national information infrastructure and GII, particularly in regions where terrestrial telecommunications infrastructure is non-existent or inadequate for high-speed communications.

83. Like most bands of the frequency spectrum, the Ka-band is shared between various services defined by ITU. Within the Ka-band allocated to FSS, different sub-bands are shared with different services, leading to constraints in system design and operation. Sharing between satellite systems requires detailed coordination between neighbouring systems and includes consideration not only of the placement of terminals, but also of the frequencies used by the radio carriers in the various systems that might be affected.

84. New non-GSO systems have been designed that can provide a wide range of services to their customers while continuing to provide protection for GSO through satellite diversity techniques.

85. There are several advantages for the international telecommunications community that GSO systems offer over non-GSO systems. Among them are tailoring of coverage to land masses, greater spectral efficiency and the availability of the resource to many different operators. The spectrum is more efficiently utilized by GSO systems than by non-GSO systems. A comparative study of GSO systems using the system architecture as a non-GSO system showed that 20 GSO systems, each providing the same worldwide service, could coexist. However, only a limited number of non-GSO systems of identical architecture could coexist because of the requirement of maintaining a minimum separation between low-Earth orbital planes.

86. For global systems, not all satellites will be uniformly loaded at all times. Geostationary satellites have an advantage because coverage spans multiple time zones and the satellite payload can shift capacity to accommodate diurnal traffic peaks. A given geostationary satellite can provide service to as many as six time zones. Although cellular and telephone systems experience peak loads of 10 per cent of the traffic in the busiest hour, the peak hourly load on geostationary satellites can be 8 per cent or less.

F. Ka-band satellites

87. Ka-band satellites represent the contribution of the satellite industry to the convergence of telecommunications, computing and broadcasting technologies. They will lead to a fundamental restructuring of the world's communications satellite industry and to the development of global satellite operators with integrated L-band, C-band, Ku-band and Ka-band systems, using GSO, LEO and MEO.

88. The Ka-band available to satellite operators involves a massive 2.5-3.5 GHz of spectrum—that is, some 4-7 times that available to some C-band satellite operators. Thus, by 1997 almost 60 proposed Ka-band projects had emerged worldwide alongside an intensified research and development effort to refine Ka-band satellite and associated technologies.

89. The policy and regulatory issues behind Ka-band satellites are far more complex and demanding than those that have hitherto faced any form of satellite communications, including DTH and DBS television, VSATs and personal communications service satellites.

90. The phrase "Ka-band satellite" is now generally recognized as a shorthand term for a new generation of communications satellites that will use on-board processing and switching to provide full two-way services to and from small Earth stations comparable in size to today's satellite television receiving dish. Such Ka-band satellite systems have also been described in other terms such as "multimedia satellites", "asynchronous transfer mode (ATM) satellites", "broadband switched satellites" and "broadband interactive satellites".

91. Ka-band satellites offer fundamentally different services from conventional communications satellites. Each Ka-band satellite will carry what is, in effect, a form of telephone "switchboard-in-the-sky". This will allow the satellite to operate like a telephone network—offering point-to-point circuits to both business and individual users at a cost far lower than available via satellite today. However, unlike a normal telephone network, such satellites will be able to offer all end-users a wide variety of services, ranging from simple narrowband through to broadband applications. They offer the prospect of a truly modern, ubiquitous and global alternative to the world's telephone infrastructure, but at a fraction of the cost of upgrading the latter to provide a comparable variety of services.

92. When the first Ka-band satellites are launched, in about three years, business and consumers will be offered services ranging from high-speed Internet access, tele-education, telemedicine, ATM-based services (including wide area networks and local area network interconnection), video-telephony, cheap videoconferencing, high-speed circuits for data communications, such as television services to aircraft, local television, cheap rural telephony, new forms of satellite news-gathering, a highly cost-effective alternative to VSAT networks, remote monitoring and many other applications that have yet to be developed.

93. There is no clearly identified major application for Ka-band satellites, but the provision of high-speed Internet and associated services is likely to be the leading market in the short and medium term. Ka-band satellites can provide the cheapest and most quickly available of all options in providing such high-speed access.

94. Ka-band satellites are likely to find a role in the mass consumer markets with "home-use VSAT" sales running into, perhaps, millions per year. Consumers are also likely to be offered combined Ku-band and Ka-band dishes capable of receiving digital satellite television services and providing two-way services.

95. The Ka-band concept offers the equivalent of a local telephone circuit where the user pays for a temporary lease of the line. The Ka-band environment provides for an alternative, charging per bit of information moved. However, such services require a lot of bandwidth because each link will usually be operating on a point-to-point basis. The prime method of using the available spectrum efficiently is to use multiple "pencil" spot beams, each covering only a small area of Earth. This allows frequency reuse in much the same way as a cellular phone network reuses spectrum.

96. The use of multiple spot beams requires on-board processing and switching to direct each transmission path between the different spot beams used for uplinking and downlinking. Similarly, intersatellite links with similar Ka-band satellites will demand switching capabilities. In effect, the on-board processing and switching capability is a network management facility. The Ka-band satellite operators will each become like telephone companies but with their telephone exchanges "in the sky".

97. The proposed Ka-band systems feature user data rates ranging from 16 kbps to as high as 1 gigabit per second (Gbps), regional and global coverage through intersatellite links, a large number of small spot beams and the use of on-board baseband processing/switching for beam interconnection. Some of the proposed systems are to provide complete, or nearly complete, global coverage. Development of these systems, however, is contingent upon overcoming significant challenges in terms of frequency coordination, technology readiness and financing. In the light of these issues, only a few of the proposed systems can be expected to be deployed by the period 2000-2005.

98. The proposed Ka-band systems will use a large number of small beams (approximately 1 degree) to deliver a relatively high (some 50 dBW) satellite effective isotropic radiated power (EIRP) to user terminals. Beam types and their quantities vary widely from system to system. Hopping beams (proposed by some systems)

provide efficient satellite resource utilization by assigning each beam to a number of dwell areas (beam spots) consisting of one major traffic area and several thin-traffic areas. Dwell time can be adjusted dynamically based on the response to the traffic demand of each beam area.

99. Fixed-beam satellites are generally simpler in design than hopping-beam satellites. However, for efficient resource utilization, coverage areas need to be adjusted to place roughly equal traffic into each beam. The number of fixed beams per satellite ranges from as few as 10 to as many as several hundred.

100. Several user terminals have been proposed for the Ka-band systems. A typical user terminal, operating at an uplink bit rate of 128-768 kbps, will employ a small aperture antenna, with a diameter of 66 cm, and a solid-state power amplifier (SSPA) of 1-3 W. All radio frequency components (SSPA, low noise amplifier, and up/down-converters) would be integrated into a small outdoor unit mounted on the reflector. Gateway terminals will employ a larger antenna, with a diameter of 2.4-5 m, and a high power amplifier of 50-200 W.

101. For the Ka-band systems to be deployed in LEO, users may be able to employ smaller antennas. However, their terminals must be capable of tracking the satellites and performing a handover once every few minutes. Satellite handover in these systems also requires precise timing coordination between satellite traffic routing and user terminal processing, as well as traffic-shaping at the user interfaces.

G. Stratospheric systems

102. There are four general telecommunications architectures that can be used to deliver broadband wireless local loop service to consumers. Two of these architectures are space-based: geostationary satellites and non-geostationary satellites. The other two are considered terrestrial—rooftop cellular-type millimetre wave repeaters and stratospheric relay platforms mounted on hovering balloons.

103. If bandwidth, antenna aperture, power and other technical factors are kept constant, the metropolitan capacity of a telecommunications system is equal to the number of spot beams that the system provides. The number of metropolitan area spot beams that a system can generate varies directly with the distance between the radio repeater and the coverage area until the line of sight approaches the outer boundary of the metropolitan area, and inversely thereafter. For example, due to the antenna size constraint, for all practical purposes a single-building top repeater can generate at most six spot beams using a 60-degree sectorial antenna. At the other end of the continuum, a geostationary satellite cannot generate more than one spot beam per metropolitan area using typical state-of-the-art antenna apertures of 5 m at 20/30 GHz.

104. A single stratospheric telecommunications platform at an altitude of 21 km can generate approximately 700-1,000 spot beams within a single metropolitan area, whereas a non-geostationary satellite at an altitude of 500 km would generate only 4-16 spot beams out to 100 km from the centre of a metropolitan area. The stratospheric architecture thus yields a metropolitan area capacity approximately 100 times greater than the non-geostationary satellite orbit architecture, assuming the same bandwidth allocation.

105. Stratospheric and other broadband systems can be differentiated into high-density and low-density market segments. All space systems (geostationary and networked non-geostationary) are low-density architectures. They do an excellent job of providing some bandwidth everywhere but cannot compete with terrestrial architectures in providing maximum capacity in metropolitan areas. Stratospheric and ground-based millimetre wave systems are high-density architectures. These designs excel at delivering metropolitan consumers the greatest value in terms of cost per unit bandwidth but are not very cost-effective when it comes to rural service.

IV. EXAMPLES OF SATELLITE TECHNOLOGY APPLICATIONS

A. Research

106. In the domain of research in agriculture, chemistry, water management, fisheries, the environment, urban planning etc., the development of networks enables researchers in developing countries to gain access to necessary information, set up teams of critical size, become integrated in the global scientific community and, in the process, stem the "brain drain".

B. Tele-education and training

107. Technologies for education and training, in particular distant education and multimedia, and new modes of learning offered by the information society may be instrumental in meeting the quantitative and structural needs of countries that have to accommodate, train and integrate large numbers of workers in widely dispersed and underequipped areas of habitation. In addition, through continuing education and training, there has to be a constant renewal of skills throughout people's lives.

C. Telemedicine and examples of its applications

108. Many stand-alone applications, such as tele-education, videoconferencing, interactive entertainment and software distribution, are being absorbed by the Internet. Telemedicine applications are more likely to operate outside the Internet. Some countries have to cope with large-scale endemics and epidemics. Telemedicine may help meet these challenges by improving the organization and management of health care. Databases may be linked through telematic networks to monitor the development of diseases (epidemiology), provide access to medical expertise through teleconsultation and pave the way for remote medical assistance. Satellite communications could also contribute to preparing and implementing health policies.

109. Mission designers, engineers and physicians of the National Aeronautics and Space Administration (NASA) of the United States worked to develop communications systems between the ground and the spacecraft so that biomedical parameters of the astronaut's physiological status could be monitored from the ground. Today, telemedicine in support of the Space Shuttle programme, the Shuttle/Mir programme and the planned International Space Station plays a significant role in maintaining the health and performance of astronauts who live and work in space.

110. As a leading user of the Internet, NASA has developed an Internet-based telemedicine test bed, Spacebridge to Russia, which links clinical experts in the Russian Federation and the United States through the Internet, a less costly approach to bringing clinical care or health information to individuals who have a need and who do not have the necessary resources to invest in a broadband, full-motion video approach offered by more expensive satellite services.

111. NASA is also developing flight hardware involving telemedicine to enhance the delivery of health care in space flight. The Instrumentation Pack is a portable pack the size of a suitcase with several clinical diagnostic tools integrated into it. NASA has unique requirements for maintaining the health of its astronauts. The technologies developed to deal with those requirements can be adapted to support several non-space activities, including rural heath care, distance learning and disaster response.

112. Satellite communications technologies used in telemedicine applications have provided a means for quality medical and health care to reach people in rural and remote areas. In developing countries in particular, often because of a shortage of health-care professionals, there is a need to create suitable links between remote clinics and urban hospitals, as well as to medical specialists in other countries. Those links also provide a means for managing patients' medical records and provide access to up-to-date health information. In conjunction with other telecommunication systems, satellites have been used in tele-consultation, image transferring, videoconferencing, and accessing medical data.

113. In May 1996, the use of satellites was demonstrated by ITU and the Midjan Group at the African Regional Telecommunication Development Conference held at Abidjan. Through a tiny camera and microphone, audio and visual signals were captured of doctors at Abidjan and sent via an Inmarsat mobile Earth station aimed at a satellite over the Indian Ocean. The signals were then transmitted simultaneously to France TELECOM and TELECOM Italia, demonstrating one type of telemedicine service involving remote consultations.

114. Transferring images is yet another example of satellite technology utilized in telemedicine services. Images may be saved as bitmaps and subsequently transmitted from a rural or remote site via a satellite link to consulting physicians. These high-resolution images are then viewed on a computer screen using a bitmap viewer or printed and saved for later reference. Through HealthNet, a telecommunications system funded by the International Development Research Centre at Ottawa, health professionals in Africa are able to access the latest developments in the medical field. Using LEO satellites, health-related information in the form of electronic messages is transmitted to and from ground stations.

115. The latest satellite phone of Inmarsat is the size of a laptop computer, making it convenient for doctors working in remote clinics and those who travel to varying locations. Priced at less than US$ 3,000, the unit offers both an affordable and a feasible solution for remote sites. The increasing use of satellites all over the world has made it possible to transmit digital data, voice messages and video images to and from remote areas. Through the use of satellites for telemedicine, quality medical and health services may be made available to persons in developing countries.

D. Meteorology services

116. Satellite-based data-collection and/or data-dissemination systems with global or multi-regional coverage play an important and increasing role within the World Weather Watch and are integrated in its Global Telecommunication System (GTS) as an essential element of the global, regional and national levels. The satellite-based communication systems are an important constituent of GTS, particularly in those geographical areas where conventional telecommunications cannot provide the cost-effective services required by members of the World Meteorological Organization (WMO). Data-collection systems are based on both public satellite-based communication services, such as Inmarsat, and data-collection missions of meteorological geostationary satellites (Meteosat, FY-2, the global Earth observation system (GEOS), the geostationary meteorological satellite (GMS) of Japan and the Indian multi-purpose satellite (INSAT) and polar-orbiting satellites (the ARGOS data collection and position location system).

117. GTS incorporates satellite-based data distribution systems, operated through the communications functions of meteorological satellites and through point-to-multi-point telecommunications services via telecommunications satellites (e.g. INTELSAT). They disseminate processed meteorological products in digital form from world meteorological centres and regional or specialized meteorological centres directly to national meteorological centres, which are received by small Earth stations at the premises of the meteorological centres. Two-way multi-point telecommunications services via satellite are also playing an increasing role in the further development and upgrading of regional meteorological telecommunications networks.

118. Several WMO members from Asia, Europe, North America, the Pacific and South America have implemented or have firm plans for the implementation of satellite-based multi-point telecommunications systems for their national meteorological telecommunications networks, which in some cases have subregional coverage. These satellite-based systems are replacing radio broadcasts, which have high recurrent operational costs and limited efficiency.

119. Communication with ships for meteorological purposes (collecting data and broadcasting forecasts and warnings) was traditionally done using the standard terrestrial maritime communications facilities, with all the attendant difficulties and lack of reliability. The advent of satellite-based maritime communications in the early 1980s, in particular the Inmarsat system, has revolutionized this process. The Global Maritime Distress and Safety System is due to be fully implemented on 1 February 1999.

120. Since the early days of flight, aircraft have relied on meteorological information for reports and forecasts of the winds and weather aloft for the safety, economy and efficiency of air navigation. In the World Area Forecast System, world and regional forecast centres provide high-quality aeronautical meteorological forecasts in uniform, standardized formats.

E. Agriculture and development communications

121. Agriculture is the cornerstone of rural society and a key to rural development. In the past, major agricultural development projects employed two-way, private radio networks to coordinate logistic activities. Satellite communications has enabled reliable telecommunications service to be offered in rural areas. Telephone communications and related technologies can play a significant role in the agricultural sector. Satellite-based radio and television can be used: (a) to broadcast weather reports; (b) to increase the awareness of new ideas and create interest in farming innovations; (c) to give timely warnings about possible pest and disease outbreaks and urgent advice on what action to take; (d) to facilitate farmer-to-farmer communications; and (e) to answer questions and give advice on problems common to a large number of farmers.

122. The value of audio/video programmes on development communications is enhanced if broadcasts are in the local language and deal with specific local issues. An operational development communications network encompassing a large number of locations in a country with diverse linguistic, social, economic and cultural identities calls for innovations in the technological, managerial, programming and social dimensions. These include the establishment and operation of community satellite terminals, research programme production in the local language, infrastructure, trained manpower and the involvement of the local people and functionaries.

V. FROM INTERNATIONAL TO GLOBAL COMMUNICATIONS

123. The move from international to global telecommunications is a move from a world in which telecommunications services between countries are provided jointly, through agreements involving national monopolies, to a world in which those services are offered by individual companies or by groups of companies in a number of countries, usually in competition with domestic suppliers. In other words, many of the major telecommunications service providers are in the process of extending their operations outside their national markets into other countries, either by establishing operations in other countries, through acquisitions and mergers, or by creating strategic alliances.

124. Questions of national sovereignty are complicated by the emergence of new telecommunications systems and services that are no longer "international", in the sense of being between individual countries, but are instead truly global. The proposed LEO mobile satellite systems are one example of this new phenomenon; another example is the strategic alliances, mergers and acquisitions that are being put in place by major national operators with the aim of offering "one-stop shopping" to customers in different countries.

125. Increasingly, these issues cannot be dealt with in isolation, as questions purely involving telecommunications policy. The globalization of telecommunications is inseparable from the globalization of economic activity. Telecommunications has unified world financial, currency and commodity markets in real-time trading systems. It has supported the development of global corporations. It is changing the distribution of work between developed and developing countries, in both the manufacturing and the service sectors. And it is having an important influence on consumer demands, expectations and tastes through the dissemination of advertising and cultural products.

126. These developments raise the critical question of how domestic and international institutions, such as ITU and its members, which are based on the premise of national sovereignty, can effectively regulate today's global, "borderless" telecommunication systems, which are largely developing in the private sector and outside the scope of government control.

VI. CHALLENGE BEFORE DEVELOPING COUNTRIES

127. The nature of telecommunications traffic itself is evolving rapidly. Voice, data and video traffic are converging into broadband, interactive multimedia. For example, the majority of Internet traffic today is text and data; but in tomorrow's environment there will be a much broader content, including full-motion video, sound and graphics for applications such as collaborative group-work, telemedicine and electronic commerce. All these applications, in turn, require access to a broadband channel. This trend is affecting both the business segment, with companies increasingly using broadband Intranet and Extranet for their communications needs, and the consumer segment, which either requires access to the Internet or, where it already has it, requires much faster access. In addition, Internet telephony technology, which uses the Internet to send audio messages between two or more computer users so that the users can converse, is slowly entering the market.

128. Early in the twenty-first century, these trends will have broadened the telecommunications market place dramatically; users in the more developed world will be focusing on information content and better access via broadband communications. The key issues will be how to get more voice, data, video and multimedia to more places and to more people directly, how to get it there faster, more cheaply and more reliably and how to package it to meet customer requirements.

129. In the developing world, the biggest challenge going into the twenty-first century will continue to be to provide ubiquitous and affordable voice and data services, as well as a reliable backbone to the developed world. A key advantage of satellites over terrestrial lines and wireless networks is the ability to build "instant infrastructure", especially in areas of the world where the terrestrial infrastructure is often inadequate or insufficient to meet the growing demands for reliable telecommunications services.

130. The level of telecommunications infrastructure in developing countries is variable but mostly far removed from the level in developed countries. The figure for teledensity (the number of installed telephone lines per 100 inhabitants) for developed countries is over 48; the figure for middle-income countries is around 10; and the figure for the least advanced countries is about 1.5. The world average is 11.5. This quantitative difference is further aggravated by qualitative weaknesses of networks affecting the quality and reliability of communications and by structural disparities between urban and rural areas. Teledensity in rural areas, for instance, does not exceed 0.8 in low-income countries. The infrastructure fails to meet local demand and cannot guarantee access to global communications networks. Moreover, defaults on payment by public administrations in certain cases, the failure to allocate charges for international communications (deductions from the national budget) and the existence of cost structures that surcharge international communications and subsidize local communications deprive telecommunications operators of the resources for their activities. Thus, public management hampers the optimum use of existing facilities.

131. However, there are enough factors for growth. First of all, there is significant sustainable demand, as evidenced by the long waiting lists and connection periods (up to 10 years), the existence of veritable black markets in telephone lines in some areas and high levels of average revenue per line. This explains why in many countries there has been sustained growth in telecommunications (e.g. more than 17 per cent a year for all countries with an average income of below US$ 700 from 1984 to 1994. The drop in the cost of technologies and competition from new global operators using call-back procedures, for example, have led to a decrease in the traditional revenue from international communications that is causing concern in developing countries, raising the awareness of current changes.

132. The number of personal computers per 100 inhabitants gives an indication of the informatics gap: it ranges from 18 for high-income countries to 2.3 for medium-income and 0.01 for low-income countries. In terms of the market share in information technology, the United States accounts for 34.7 per cent, Europe for 29.3 per cent, Japan for 14.6 per cent and the rest of the world for only 21.4 per cent. These differences are also reflected in the figures for data transmission, the spread of Internet servers and the number of users. Here, again, there are enough factors for potential growth, including the drop in prices, the development of multimedia applications and access to the Internet. The personal computer market is dynamic and could follow in the

footsteps of television, which is now widespread in low-income countries, where 46 per cent of homes have a television set.

133. According to the World Bank, the annual investment necessary for the growth of telecommunications in the developing countries over the next five years amounts to US$ 60 billion. Financing in the form of international public aid would not exceed US$ 2 billion or US$ 3 billion, and most countries cannot make up the difference. The necessary investment can only come from the private sector. However, to mobilize private investors, a legislative and regulatory framework will have to be established that is stable, predictable and transparent, making it possible for rational economic decisions to be taken.

134. For many years, the developing nations attempted to expand their networks and to provide basic telephone services using financing models derived from developed countries—models such as cross-subsidies from international and long-distance services to local services. Developing countries did that in the genuine belief that monopoly was the most effective market arrangement for achieving universal service. However, their efforts fell far short of that goal.

135. The absence of a sound, developed telecommunications infrastructure can affect a nation's entire economy. Since it is not cost-effective to deploy telecommunications in poor countries that might benefit most from it, it follows that economic investment most likely will not go to regions with inadequate telecommunications infrastructure.

136. The undeveloped infrastructure of rural areas is also forcing people to migrate into increasingly congested urban areas in search of opportunities; currently, the world's urban population is growing by 170,000 each day. This mass migration can bring negative consequences and result in further economic and environmental deterioration. Even in developed countries, the lack of services in rural regions may lead to population concentration; for example, 20 per cent of the population of France resides in the Paris area and 40 per cent of the population of Greece lives in the Athens area.

137. It is important to understand that technology and communications limitations in underdeveloped regions are only one reason for the concentration of computers and Internet services in the developed countries. Technology and rapid communications service are much more crucial in a highly developed country than in a developing country. There can be political, cultural and even religious reasons for avoiding links to a worldwide, open communications network.

138. Despite 100 years of progress in telecommunications, nearly 4 billion of the world's 5.7 billion people continue to be denied the basic human right to communicate because they lack access to the most basic telecommunications services, developing countries having only 3 per cent of the number of telephones in developed countries. Fifty per cent of the world's population has never made a phone call and lives two hours from the nearest phone. By the year 2000, 40 per cent of the world's population will be in China, India and Indonesia. Those nations currently have only 6 per cent of the world's phone lines, even though China adds a telephone network equal to France's national system every two years.

139. Many developing countries in Africa, Asia and Latin America have a great need for external funding to provide basic telecommunications to accelerate their socio-economic development. Some 85 countries have a telecommunications penetration of less than 1 per 100 of population. The current forms of assistance to this critical sector are clearly inadequate. In the last 40 years, less than 2 per cent of World Bank lending has been for telecommunications. The World Bank itself estimates that the developing world needs at least US$ 30 billion annually to satisfy excess demand by the year 2000.

140. The "contribution" of a telephone to gross national product (GNP) is greater the lower the per capita GNP. Therefore, the less developed a country is, the greater the influence of one telephone on GNP. In order to provide the most effective possible support for growth, telecommunications must develop at a rate that is greater than the rate of economic expansion.

141. While most African countries are experiencing some extension and modernization of their telecommunications networks, the teledensity of sub-Saharan Africa has continued to remain at less than 1 per 200 inhabitants; most of the telecommunication network is analog and many sections are highly unreliable, especially during the rainy season. Africa has the least developed infrastructure, accounting for only 2 per cent of the world's telephones and 12 per cent of the population. Latin America accounts for 6 per cent of the lines and 18 per cent of the population, and Asia accounts for 13 per cent of the lines and 57 per cent of the population.

142. In Africa the state of the existing telephone networks varies greatly from country to country. Some African countries have made telecommunications a priority and are installing digital switches with fibre-optic inter-city backbones and the newest cellular and mobile technology. For example, national networks in Botswana and Rwanda are among the world's most sophisticated, where 100 per cent of the main lines are digital, compared with 49.5 per cent in the United States. At the other end of the scale, countries such as Madagascar and Uganda have highly unreliable analog telephone systems and poor national links between urban centres. Some countries, such as the Democratic Republic of the Congo, Mali and the Niger, have only one telephone line for every 1,000 inhabitants.

143. Africa has been searching for ways of harnessing its great potential to build a common network that will give it a place in the information society. The Africa ONE project involves a submarine fibre-optic ring that will literally encircle the African continent, extending 35,000 km and connecting its coastal and landlocked countries, as well as its islands.

144. Africa needs to reduce its high transit costs and improve its telecommunications with modern technology. Direct connectivity throughout the continent is still very limited. A large proportion of inter-African telephone traffic continues to be transited through transit centres outside the continent. It is estimated that between US$ 300 million and US$ 400 million are lost by African countries each year as a result.

145. One example of how international Internet service via satellite may benefit Africa can be found in Uganda. In that country, it costs US$ 4 per page to send a facsimile, and sometimes it takes two hours to find an open outside line, but it costs only $0.05 per page to use an e-mail-based facsimile server for the identical traffic.

146. The growth rate in the number of telephone lines in Asia and the Pacific has surpassed that in every other region of the world since 1990. The low-income countries in that region have registered growth of close to 30 per cent a year. Despite that rapid growth, the teledensity of developing countries in Asia and the Pacific is still well below that of the Arab countries or Latin American countries. As a result, Governments in Asia and the Pacific are increasingly turning to private capital for the construction of local telephone networks.

147. The number of cellular subscribers in Asia and the Pacific increased by 84 per cent in 1996, compared with an increase of 14 per cent in fixed telephone lines and an increase of 11 per cent in international telephone calls. The number of cellular subscribers has increased by 40 million since 1990 and the region now accounts for one third of the world total. Some 17 of the 38 main economies in the region now permit competition in the provision of cellular services and, by mid-1997, there were 113 different companies operating in that area, compared with just 50 in 1992.

148. Latin America is experiencing some of the fastest-moving telecommunications deregulation and infrastructure modernization observed today among the emerging economic regions of the world. In 1990, most Latin American countries had fewer than five installed telephone lines for every 100 inhabitants. Today, the average teledensity in the region is approximately 13.3 installed lines per 100 inhabitants. Since 1990, the number of installed lines has grown at an average rate of 11 per cent in the seven countries in the region with the largest markets: Argentina, Brazil, Chile, Colombia, Mexico, Peru and Venezuela. Those seven countries account for 83 per cent of the total population of Latin America and account for approximately 89 per cent of the total telecommunications service revenue in the region.

149. Economic structures, methods of organization and of production, individual access to knowledge, recreation, work methods and social relations are changing due to the emerging global information economy. The information revolution is progressing fast because the new information technologies are evolving rapidly. Corporate and government information systems are undergoing changes, management requirements are calling for faster availability of information, and the means of handling and delivering information are proliferating.

150. Telecommunications and information technologies are creating new possibilities for improving the social, political and economic development of countries. Communications systems combined with advanced information technologies are the keys to the information society. Communications satellites, which play a crucial role in GII, have four advantages:

(a) Ubiquity: satellites, particularly those with powerful and flexible spot beams, can provide cost-effective point-to-multi-point distribution across widely dispersed geographical areas;

(b) Mobility: on land, particularly in remote areas, at sea and in the air, satellites are the only means of providing reliable communications;

(c) Distance insensitivity: unlike all terrestrial modes of communications, the cost of satellite communications is relatively insensitive to whether a transmission is local, regional or international;

(d) Resiliency: satellites are not affected by natural catastrophes (earthquakes, volcanoes, tornadoes etc.) or man-made disasters (wars, environmental destruction etc.) and, for that reason, satellites will always be called upon to provide critical redundancy to vital terrestrial communications networks.

151. Time and distance constraints have been removed by satellite networks that carry information; basic services such as e-mail and interactive video, which allow people to use the networks for applications such as distance learning, telemedicine and tele-working, offer dedicated solutions, particularly to developing countries. Furthermore, satellites that are well adapted to transporting every type of information offer new possibilities such as broadcasting and multiple destinations. It is important for the developing countries to understand the implications and capabilities of these new technologies, to gain experience, to plan and to adopt the technologies judiciously and advantageously in order to meet their specific requirements.

152. The technologies, products and services that would permit developing countries to participate in GII already exist. Developing countries could be the primary beneficiaries of the potentials of information technology. Social benefits include the provision of education and training where teachers are unavailable, the delivery of high-quality medical information and health care for the sick, and cultural integration. Economic benefits include monitoring international market price information on tradeable goods, instant market transactions, financial services, electronic commerce, and information on environmental conditions, all of which are vital in trade and in the global competitive environment.

153. Creating the proper environment for the successful implementation of sophisticated networks in order to enable universal access to advanced information technologies will be the major challenge to developing countries. Embracing the goals aimed at integration into the globalization process, developing countries will also face the challenge of enhancing their capacity for development with access to the full benefits to be derived from world trade, foreign direct investment and other private financing. In addition, developing countries will face the challenge of striking a balance between their domestic priorities for economic and social development and the requirements for maintaining and extending the benefits from international trade. Those challenges entail assessing which sectors of the industry and government activity should receive priority for information and communications services development and application and identifying the sectors in which applications of information and communications services can help to overcome significant bottlenecks to economic and social development. Meeting those challenges may, in turn, entail introducing changes in the public policy domain and legislation, where national cooperation would be required, and subsequently international cooperation as countries link to GII.

154. Developing countries must adopt a deliberate and consistent course towards making their telecommunications networks completely digital. By going digital, however, not only will the networks of developing countries be compatible with those of the rest of the world but also the necessary skills will be built up to deal with the complexities of the era of convergence of telecommunications, computers and entertainment.

155. Developing countries must create national regulatory environments that permit satellite communications to thrive. Satellite communications technology has traditionally been a "by-pass" technology; it does not fit well within institutional structures that have been set up in the era of wireline services. Satellite communications will thrive where the communications and information sectors have been reformed to permit variety, ubiquity and service to the customer.

VII. CONCLUSION

156. The world's rapidly growing telecommunications markets (they are expanding by some 6-7 per cent in developed countries and by some 9-10 per cent in developing countries) are becoming increasingly competitive. Only the best technologies and operating systems will survive. It is therefore important for satellite communications technologies to gain ground rapidly, given the high rate of innovation in fibre-optic-based systems.

157. Since its introduction in 1965, satellite communications has transformed local, national and international life and has contributed to a better understanding among people in spite of physical boundaries. Technological developments offering enhanced satellite services will continue to bridge the development gap between developed and developing countries and between densely and sparsely populated areas in individual countries.

158. Today, the world is witnessing the emergence of the third great revolution in history—the information revolution—after the agrarian and industrial revolutions. Satellites are one of the essential technologies for information-intensive networks such as the Internet, the backbone of GII. Satellite communications will play a crucial role in GII and a supportive role in the global information economy. Satellite communications will be an essential component of political, economic, social and cultural developments, facilitating the creation of a more equitable society.

159. Remarkable breakthroughs in both space and ground communications systems will undoubtedly emerge in the twenty-first century, allowing increased mobility, a wider range of personalized and interactive services, broadband services, and more equal access to ubiquitous services.